U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF LAND MANAGEMENT - ALASKA

DIVISION OF MINERAL RESOURCES

BRANCH OF MINERAL ASSESSMENT

KOYUKUK NATIONAL WILDLIFE REFUGE OIL AND GAS ASSESSMENT

by

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Koyukuk National Wildlife Refuge has a low hydrocarbon (oil and/or gas) occurrence potential with a low level of certainty, BLM classification of L/A. The refuge has no development potential at this time.

Illustrations

List of Tables

INTRODUCTION

The Koyukuk National Wildlife Refuge (NWR) Oil and Gas Assessment will be used in the decision making process related to the "comprehensive conservation plan" for the refuge, which is mandated by Sections 1008 and 304(g) of the Alaska National Interest Lands Conservation Act (ANILCA). The U.S. Bureau of Land Management (BLM) is conducting the resource assessment at the request of the U.S. Fish and Wildlife Service (FWS) as set forth in a Memorandum of Understanding between the FWS and BLM (Appendix A).

This assessment will:

1. Describe the geology of Koyukuk NWR.

2. Discuss the hydrocarbon occurrence potential of Koyukuk NWR.

3. Discuss a hypothetical development scenario within Koyukuk NWR.

4. Present an economic assessment of oil and gas production from the Koyukuk NWR.

The Koyukuk NWR contains approximately 4.5 million acres. The refuge is located along the lower reaches of the Koyukuk River in west central Alaska, just to the north of the community of Galena (figure 1).

DESCRIPTION OF GEOLOGY

Previous Work

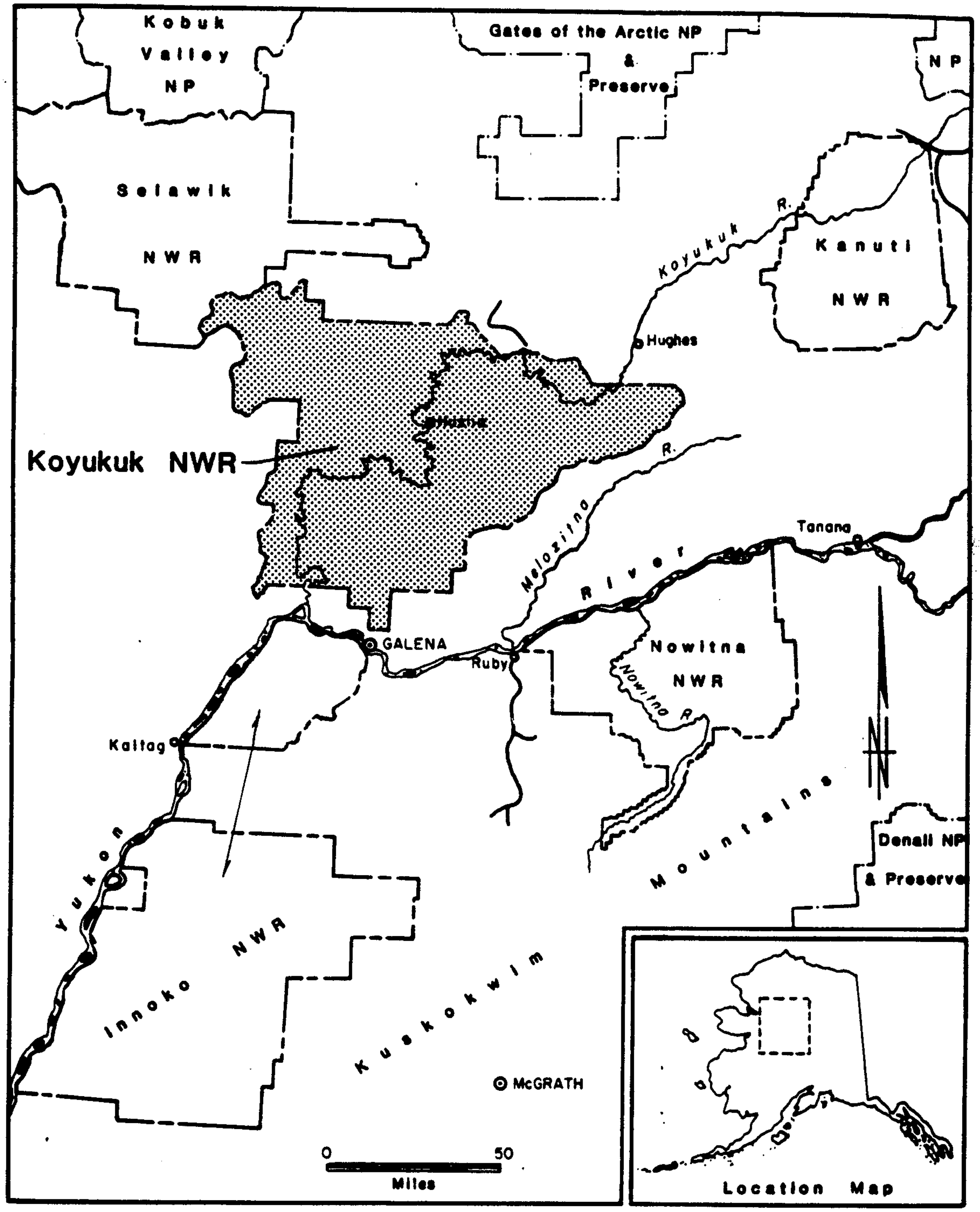
As with many areas in Alaska, the military conducted the first recorded exploration of Koyukuk Flats. In 1885, Lieutenant H. T. Allen and his party mapped the Koyukuk River from the mouth of the John River to the Yukon River (Smith, 1913).

The first geologic exploration of the area occurred in 1899, when a party under the command of F. C. Schrader, of the U.S. Geological Survey, descended the Koyukuk River to the Yukon and geologically mapped the area (Smith, 1913).

Since these early explorations, many geologists, both government and industry, have worked in and around the area of Koyukuk NWR. The U.S. Geological Survey geologically mapped the area on a regional basis during the late 1950s and 1960s. Little work has been done on the hydrocarbon potential of the area.

Physiography

Koyukuk NWR lies mostly within the Koyukuk Flats section of the Western Alaska province of the Intermontane Plateaus physiographic division


Kobuk
Valley
NP
Gates of the Arctic NP
&
Preserve
NP
Selawik
NWR
Koyukuk R.
Kanuti
NWR
Hughes
Koyukuk NWR
R.
Melozitna
Tanana
River
GALENA
Ruby
Nowitna
NWR
Nowitna R.
Kaltag
Yukon
Mountains
Denali NP
& Preserve
Innoko NWR
Kuskokwim
McGRATH
0
50
Miles
Location Map

(figure 2). The western edge and northwestern corner, the northern edge, and the eastern edge of the refuge lie within the Nulato Hills, Pah River, and the Indian River Upland sections of the Western Alaska province, respectively.

The Koyukuk Flats section is an extensive lowland at the junction of the Koyukuk and Yukon Rivers. Meander belts, five to ten miles wide, form the central portion of a five- to twenty-mile-wide belt of flat plains along the rivers. The ground slopes gently from these flat plains to the surrounding uplands. The meander belts contain numerous meander-scroll and some oxbow lakes, while the surrounding flat plains contain abundant thaw lakes. The area between the plains and the surrounding uplands is partly covered by eolian deposits and contains some thaw lakes (Wahrhaftig, 1965).

The Nulato Hills section, a series of northeast-southwest trending ridges with rounded summits and gentle slopes, has summit altitudes ranging from 1,000 to 2,000 feet in altitude, with local relief of 500-1,500 feet. Narrow flat-floored valleys are generally incised in their upstream portions. Few thaw lakes occur in this section (Wahrhaftig, 1965).

The Pah River section contains mountains, plateaus, and lowland flats. The mountains, up to 4,000 feet in altitude, have gently rounded ridges at the lower altitudes. The once-glaciated summits of the mountains have a rugged topography. Some cirque lakes occur in the higher altitudes. The broad, rolling plateaus range in altitude from 500 to 1,500 feet. The lowland flats, five to ten miles wide, contain numerous thaw lakes (Wahrhaftig, 1965).

The Indian River Uplands have gently rounded ridges with accordant summits between 1,500 and 2,000 feet in altitude. Within the refuge they tend to be parallel and trend northeast-southwest. A few summits reach 4,000 feet in altitude. The divides between the ridges are broad and flat. The divides, valleys, and the passes have numerous thaw lakes (Wahrhaftig, 1965).

Rock Units

Koyukuk NWR lies entirely within the Yukon-Koyukuk province (YKP). The YKP is not the simple sedimentary basin of Payne (1955) and Miller, Payne, and Gryc (1959). It is a highly mobile tract subjected to repeated volcanism and plutonism during Cretaceous and Tertiary times (Patton, 1973).

The area studied for this report includes the mafic volcanic and intrusive rocks and the metamorphic complexes to the east of the YKP. These rocks were the source of many of the sediments in the refuge. An understanding of the processes that formed these rocks is crucial to understanding the processes that occurred within the refuge.

Cretaceous (144 to 66.4 million years old, Ma) granitic rocks have intruded the rocks of the YKP, which consist chiefly of volcanogenic sediments and andesitic volcanics of Cretaceous age. Late Cretaceous and Cenozoic

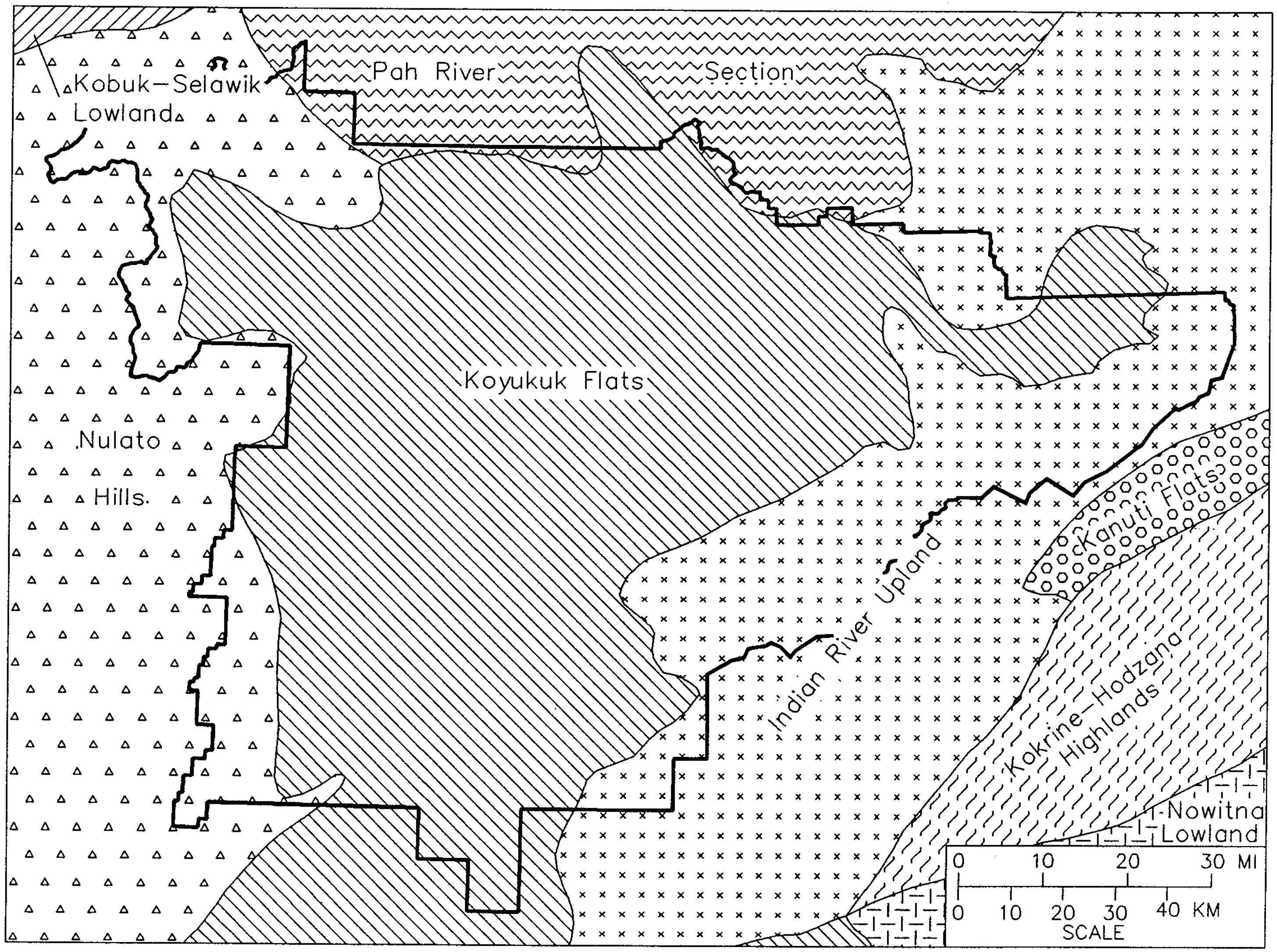


Figure 2. Major physiographic divisions of Koyukuk NWR (from Wahrhaftig, 1965).

(younger than 97.5 Ma) volcanic rocks locally overlie the older rocks of the YKP. Sedimentation was limited to a single episode in mid-Cretaceous (113 to 91 Ma) time (Patton, 1973). A volcanic or volcanogenic province, rather than a sedimentary basin, best describes the YKP.

Rocks in the study area range in age from Precambrian(?) (older than 570 Ma) to Quaternary (younger than 1.6 Ma). See figure 3 for a generalized stratigraphic column of the YKP. Figure 4 contains an east-west cross section that shows the structural relationships of all the rocks within the refuge.

Precambrian to Devonian (older than 360 Ma)

The eastern portion of the study area (outside the refuge), partially composed of a metamorphic complex, wraps around the younger central portion of the YKP and merges with the Ambler schist belt of the southern Brooks range. Patton, Tailleur et al. (1977), assigned a Devonian or older(?) (older than 360 Ma) age to the Ambler schist belt, while Forbes, Carden et al. (1979) and Turner, Forbes, and Dillon (1979) assigned it a Late Precambrian (900 to 570 Ma) age. As Patton et al. (1978), indicate that the metamorphic complex along the eastern edge of the study area has a Paleozoic and_or Precambrian (older than 245 Ma) age, it may form part of the Ambler schist belt or be an equivalent unit. This metamorphic complex contains mostly greenschist facies rock that locally contains blueschist mineral assemblages (Patton, Tailleur et al., 1977, and Forbes, Carden et al., 1979). These rocks include quartz-chlorite-muscovite schist, micaceous quartzite, glaucophane- chlorite-muscovite schist, quartzite, quartz-mica schist, and marble. Higher rank metamorphic rocks (almandine-amphibolite facies), present near granitic intrusions, include quartz-feldspar-biotite gneiss, and quartzite (Patton et al., 1978).

Permian to Jurassic (286 to 144 Ma)

Large exposures of mafic volcanic and intrusive rocks occur in the eastern part of the study area. These rocks, apparently part of an ophiolite sequence, comprise pillow basalt, diabase, gabbro, radiolarian chert, serpentinized peridotite and dunite, and slate. All of the volcanic and intrusive rocks have undergone metamorphism to the greenschist facies, forming greenstone. Some of these rocks have been intruded into the older metamorphic complex, or tectonically emplaced in them.

Lower Cretaceous (144 to 119 Ma)

Marine andesitic volcanic rocks, that apparently underlie nearly the entire province, form the base of the Cretaceous (144 to 66.4 Ma) sequence in the northern YKP (Patton, 1973). Aeromagnetic profiles suggest that they may also underlie the Koyukuk Flats at shallow depths (Gates et al., 1968). This assemblage of rocks, comprised predominantly of

<table>
<tr><th>AGES</th><th>STRATIGRAPHIC UNITS</th></tr>
<tr><td>QUATERNARY</td><td>Basalt, glacial drift, waterlaid and windblown silt deposits</td></tr>
<tr><td rowspan="2">43–44Ma
TERTIARY
50–65Ma</td><td>Basalt ± Felsic Volcanic Rocks</td></tr>
<tr><td>Felsic Volcanic Rocks ± Basalt</td></tr>
<tr><td rowspan="3">MIDDLE–LATE
CRETACEOUS</td><td>Quartz conglomerate, sandstone, shale, and coal (nonmarine marginal trough deposits)</td></tr>
<tr><td>Graywacke, mudstone, shale, conglomerate, tuff, and coal (fluvial–deltaic deposits)</td></tr>
<tr><td>Volcanic graywacke, conglomerate and mudstone (flysch deposits) intruded by 79–89ma calc–alkaline plutonic rocks</td></tr>
<tr><td>NEOCOMIAN</td><td>Andesitic volcanic rocks and volcanogenic sediments intruded by 100–113ma alkalic plutonic rocks</td></tr>
<tr><td>JURASSIC
TO
PERMIAN</td><td>ANGAYUCHAM TERRANE
Pillow basalt, gabbro, serpentinized peridotite and dunite, chert and slate</td></tr>
<tr><td>DEVONIAN
TO
PRECAMBRIAN</td><td>RUBY TERRANE
Pelitic schist and carbonate rocks</td></tr>
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Figure 3. Stratigraphic column of Koyukuk NWR (after Patton, 1973, in Harris, 1987).

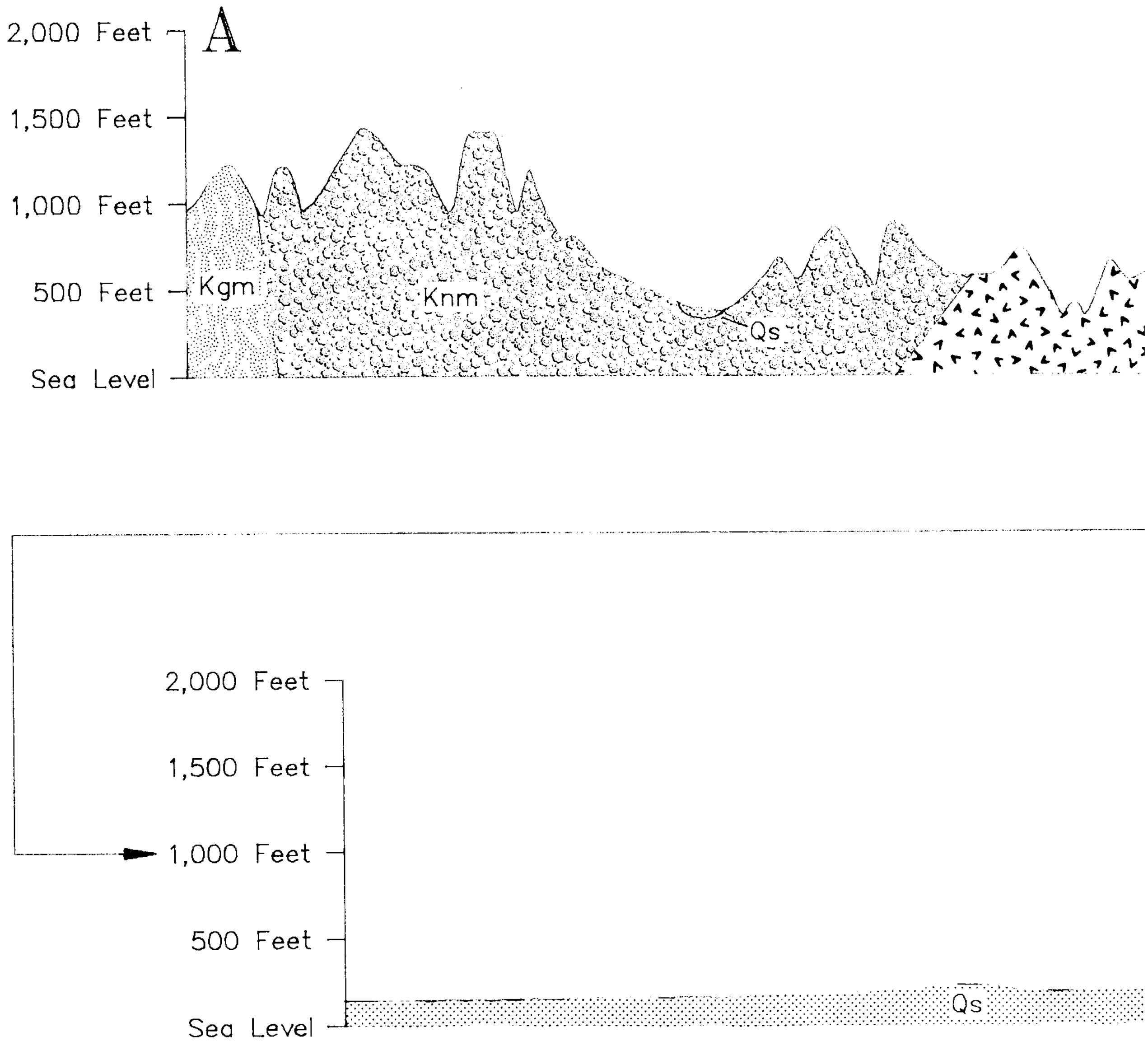
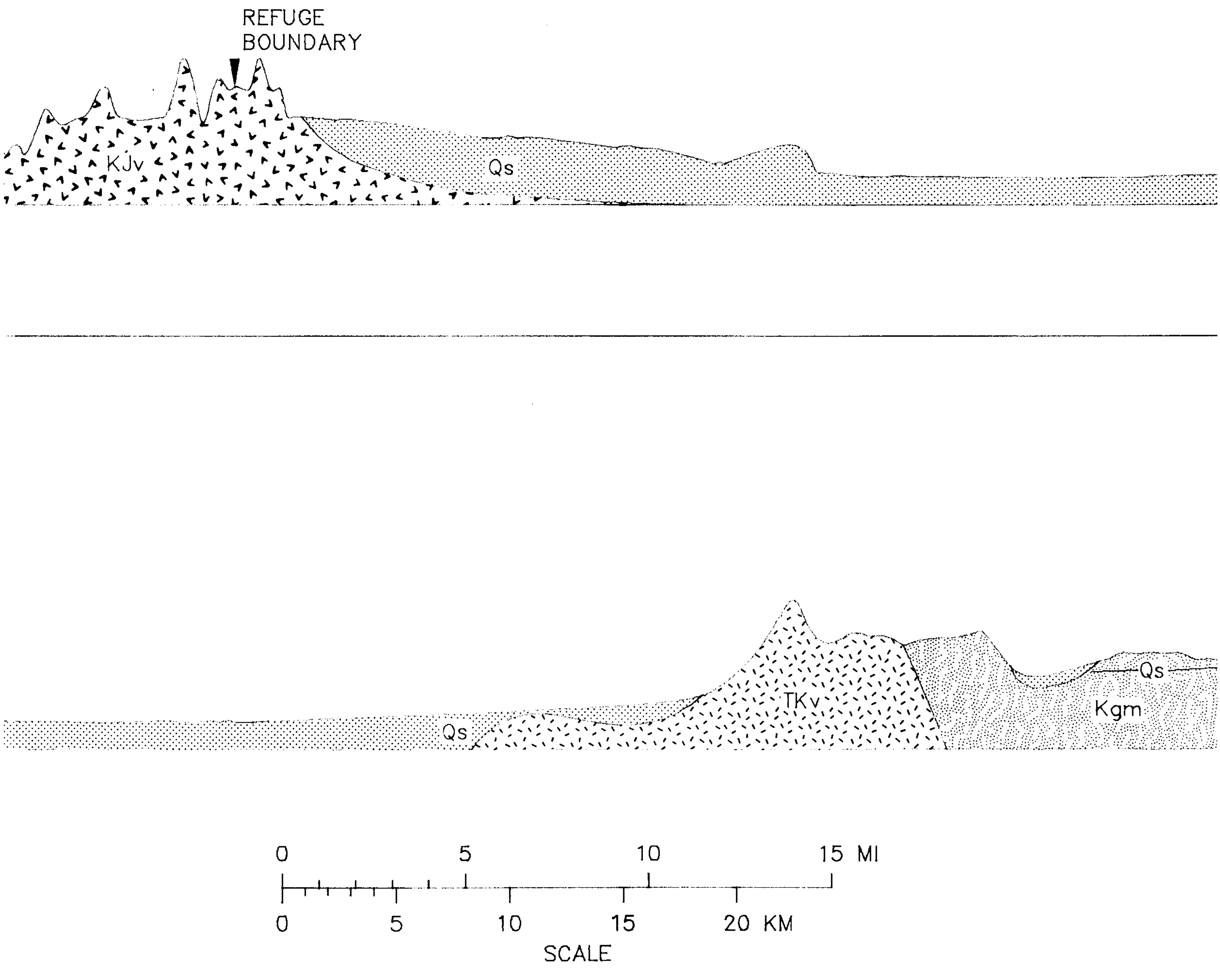
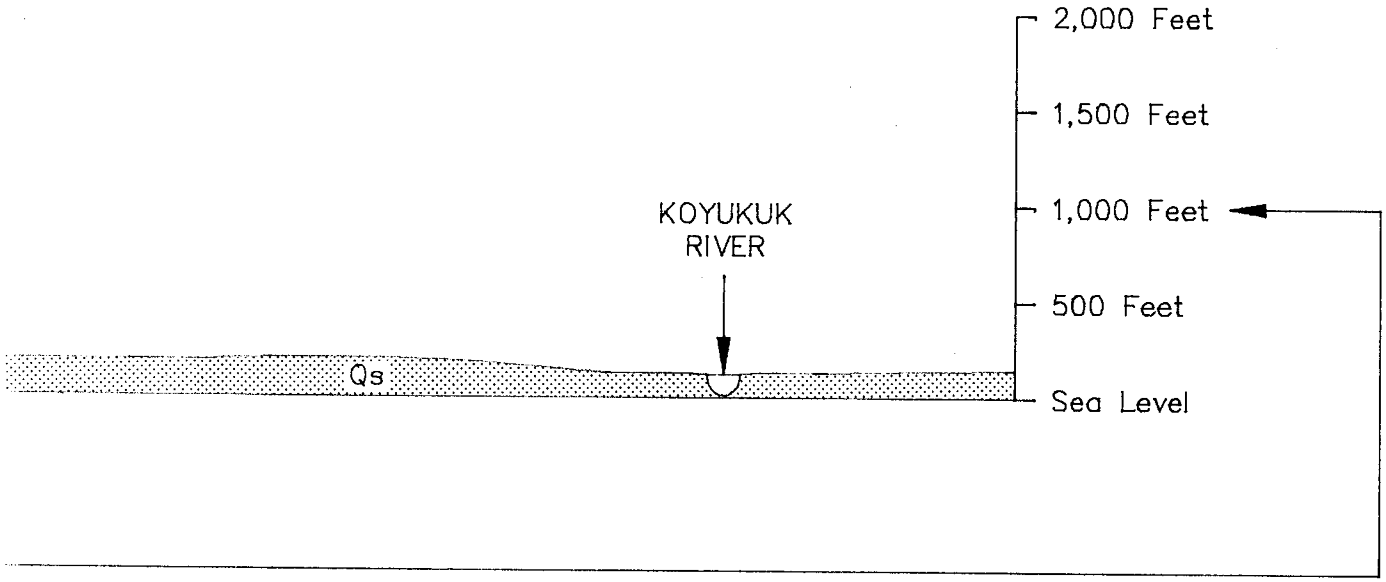
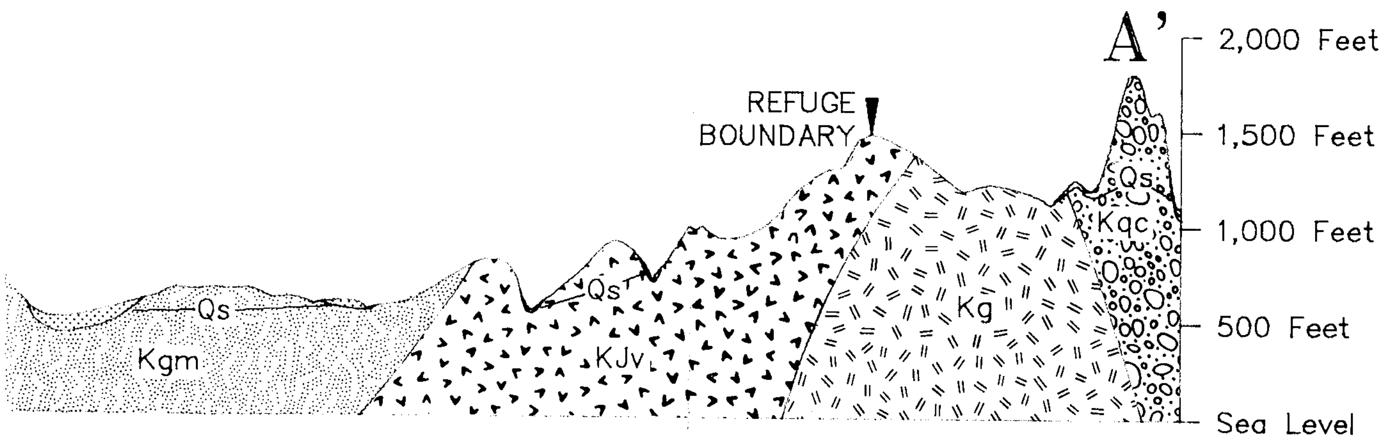


Figure 4. Cross se
explanation



oss section A–A', a east–west cross section through Koyukuk NWR. See Plate 1 for location of section
ition of geology. Horizontal scale = 1:250,000. Vertical scale = 1:12,000. Vertical exaggeration = 20.





location of section and for
exaggeration = 20.8.

volcaniclastic rocks, contains porphyritic pyroxene andesite flows and fine grained intrusive rocks. The volcaniclastic rocks of the assemblage include crystal and lithic tuffs, massive breccias, agglomerates and conglomerates, and tuffaceous graywacke and mudstone. Along the Hogatza plutonic belt (northern part of the study area), the volcanic rocks have been propylitically altered to a hard, pale-green hornfels (Patton, 1973).

Cretaceous (144 to 66.4 Ma)

Cretaceous terrigenous sedimentary rocks underlie a large portion of Koyukuk NWR. During Lower Cretaceous (Albian, 113 to 97.5 Ma) time, thick sequences of marine turbidites, chiefly volcanic graywacke and mudstone, accumulated under the refuge. These sediments, known to be as much as 5,000 feet thick, may exceed 20,000 feet to the southwest of the refuge (Patton, 1973). As least 10,000 feet of sandstone, siltstone, shale, and coal of mid-Cretaceous (Albian and Cenomanian, 113 to 91 Ma) age overlie the Lower Cretaceous turbidites in the refuge. These rocks may overlap the andesitic volcanic rocks that were the source for the older turbidites along the eastern side of the refuge. In the northeastern corner of the refuge, up to 3,000 feet of nonmarine conglomerate of Upper Cretaceous (Santonian(?) and Campanian, 87.5 to 74.5 Ma) age unconformably overlie the mid-Cretaceous rocks. These rocks also contain subordinate amounts of quartz sandstone, shale, thin bituminous coal beds, and ash fall tuffs (Patton, 1973).

The Hogatza plutonic belt extends across the northern part of the refuge (plate 1). This belt of granitic rocks contains several separate plutons having compositions ranging from monzonite, to syenite, to quartz monzonite, to granodiorite, with some minor alkaline subsilicic rocks. The Plutons intrude both the Lower Cretaceous andesitic volcanic rocks and the Lower Cretaceous sedimentary rocks. They appear related, both spatially and temporally, to the Upper Cretaceous felsic volcanic rocks.

Upper Cretaceous to Lower Tertiary (97.5 to 23.7 Ma)

Extrusive and intrusive felsic rocks, chiefly latite and rhyolite, were emplaced in the YKP in Upper Cretaceous and Lower Tertiary time. Subaerial flows and tuffs, up to 2,000 feet thick, overlie the earlier Cretaceous andesitic volcanic rocks and sedimentary rocks. Locally, swarms of small sills, dikes, and plugs of latite and rhyolite pervasively intrude the older volcanic and sedimentary rocks.

Tertiary (66.4 to 1.6 Ma)

Non-marine and shallow marine sediments filled several small structural or topographic basins in the YKP during Tertiary time. One of these basins is the basin underlying the Koyukuk Flats (Patton, 1973).

Upper Tertiary(?) to Quaternary (younger than 23.7 Ma)

In the northern part of the study area, flat lying flows of olivine basalt, may reach 500 feet in thickness. Wind-blown silts and glacial drift frequently mantle the flows (Patton, 1973).

Quaternary (younger than 1.6 Ma)

Sequences of alluvium, eolian deposits, flood plain deposits, and glacial drift of Quaternary age cover all of the river valleys and lowlands in the study area. The eolian deposits include the Nogahabara Sand Dunes. The flood plain deposits may reach significant thicknesses in the major river valleys.

STRUCTURAL GEOLOGY AND TECTONICS

Structural Geology

Miller, Payne, and Gryc (1959) and other early workers thought that the Yukon-Koyukuk geosyncline and the Hogatza arch underlaid the refuge area. These structures are now assigned to the Yukon-Koyukuk geological province (YKP).

Two Cretaceous (144 to 66.4 Ma) sedimentary basins, separated by a structural high of volcanic rocks, form the structural framework of the study area (figure 5). The Kobuk-Koyukuk Basin underlies the southeastern side of the refuge. The Lower Yukon Basin underlies the western edge of the refuge. The portions of the Lower Yukon and Kobuk-Koyukuk Basins within the refuge are now topographically higher than most of the structural high between them.

A possible Cenozoic (younger than 66.4 Ma) structure superimposes upon the older Cretaceous structures (Patton, 1973). Koyukuk Flats may represent a Cenozoic structural depression. Aeromagnetic profiles across the Koyukuk Flats and surface mapping indicate thin Cenozoic sediments in this depression (figure 6) (Patton, 1973). The minimal thickness of sediments in the Koyukuk Flats indicates that the sediments may have simply accumulated in a topographically low area.

Intense deformation, steep dips, tight folds, and closely spaced high angle faults characterize all pre-Tertiary (older than 66.4 Ma) rocks in the northern YKP (Patton, 1973). In the study area, the folds and faults generally trend northeast-southwest. Deformation in the YKP increases with the age of the rocks, as the YKP has undergone several periods of deformation (Harris et al., 1987).

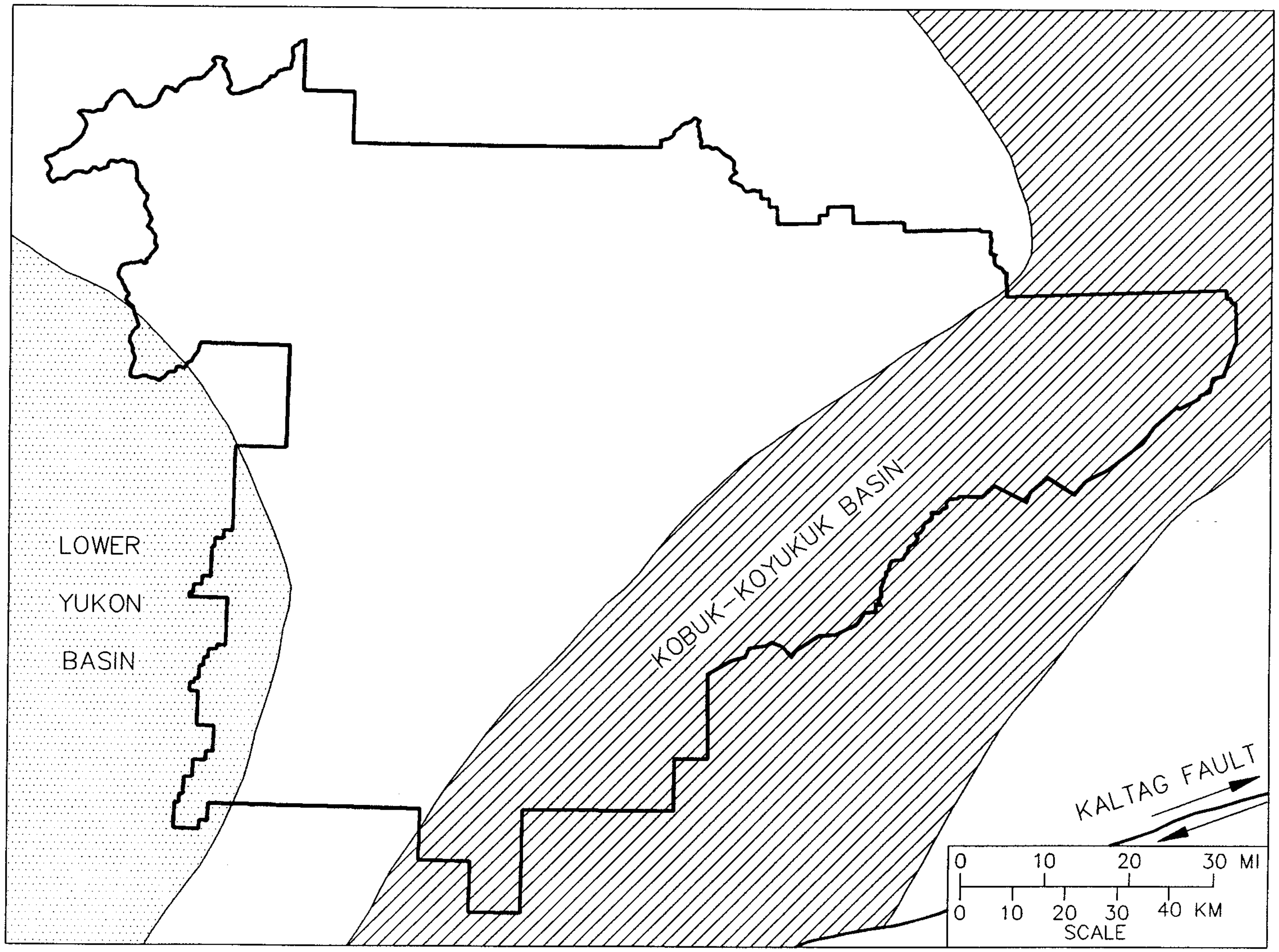


Figure 5. Major structures of Koyukuk NWR (from Patton, 1973).

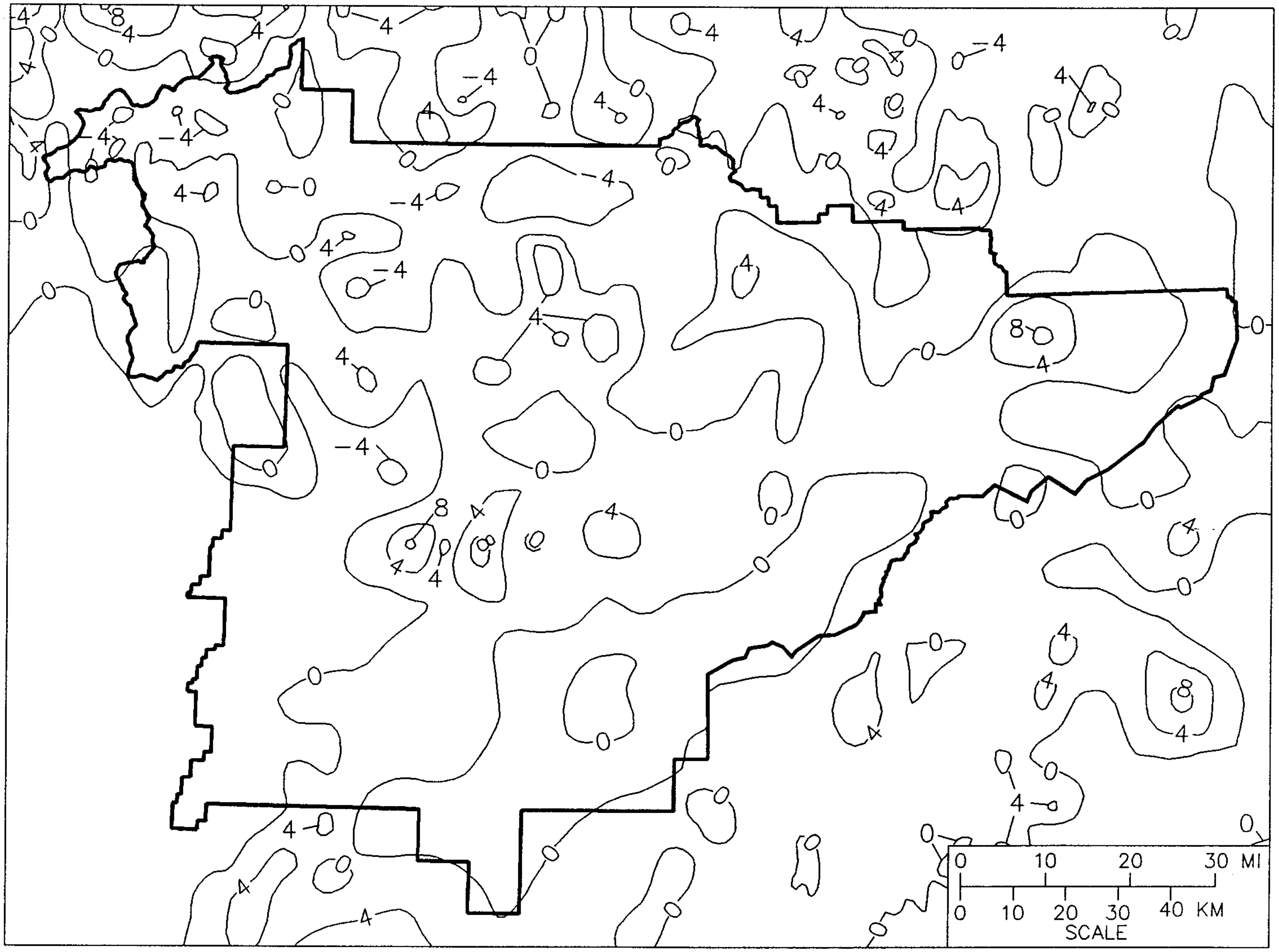


Figure 6. Simplified magnetic anomaly map of Koyukuk NWR (after Godson, 1984). (contour interval = 400 gammas / contour lables times 100)

Tectonics

The Yukon-Koyukuk geologic province (YKP) corresponds to the Koyukuk lithotectonic terrane of Jones, Silberling, Coney, and Plafker (1987). (A terrane, a fault-bounded geologic entity of regional extent, is characterized by a geologic history which differs from the histories of contiguous terranes (Jones et al., 1985).) The study area also contains portions of the Angayucham and Ruby terranes. Figure 7 shows the locations of these terranes. A portion of the Innoko terrane is shown in the mapped area, but it is not part of the study area.

Patton (1975) thought the Koyukuk terrane originated as a rift zone. The oldest rocks in the terrane (basalt, diabase, gabbro, and ultramafic rocks; apparently an ophiolite sequence) may represent oceanic crust and mantle material from the floor of the rift. Cretaceous volcanics and intrusives overlie this oceanic crust and make up most of the rock exposed in the study area.

The Angayucham terrane, a structurally and stratigraphically complex assemblage of oceanic rocks, includes gabbro, diabase, pillow basalt, tuff, chert, graywacke, argillite, and minor limestone. Ultramafic plutonic rocks have been tectonically emplaced throughout the terrane (Jones, Silberling, Coney, and Plafker, 1987).

The Ruby terrane is a structurally complex and polymetamorphosed sequence of middle Paleozoic and older (older than 360 Ma) carbonate rocks, calc-schist, quartz-mica schist, quartzite, metarhyolite, chert, and argillite (Jones, Silberling, Coney, and Plafker, 1987).

The Ruby terrane, the oldest of the three terranes, may represent basement for the entire YKP (Gemuts et al., 1983). The rocks of the Angayucham terrane were thrust over the Ruby terrane in Late Jurassic or Early Cretaceous time (163 to 97.5 Ma). An oceanic arc, the Koyukuk terrane, collided with the continental margin during the same time period. Outliers of Angayucham terrane rocks in the Brooks Range indicate that the Angayucham terrane once extended much farther than at present. Angayucham terrane rocks probably form the basement under the YKP. Figure 8 presents a pictographic representation of the events discussed above.

Geologic History

The rocks and sediments in the study area for the Koyukuk NWR oil and gas assessment range in age from Precambrian to Recent. The oldest rocks occur east of the refuge in the Ruby terrane. The rocks of the Angayucham and Koyukuk terranes range in age from Paleozoic to Recent (younger than 570 Ma).

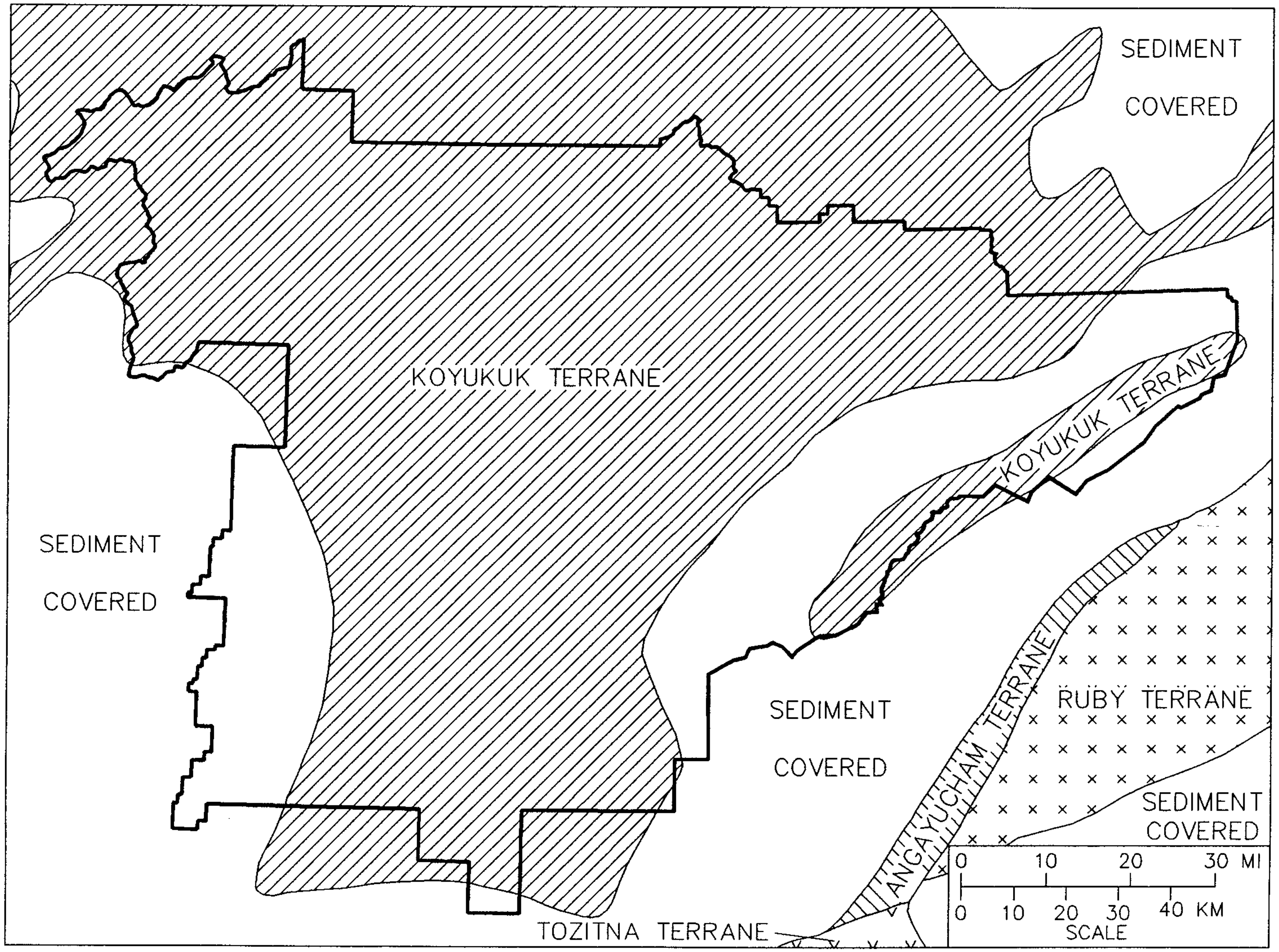


Figure 7. Tectonostratigraphic terrane mapy of Koyukuk NWR (after Jones, Silberling, Coney, and Plafker, 1987).

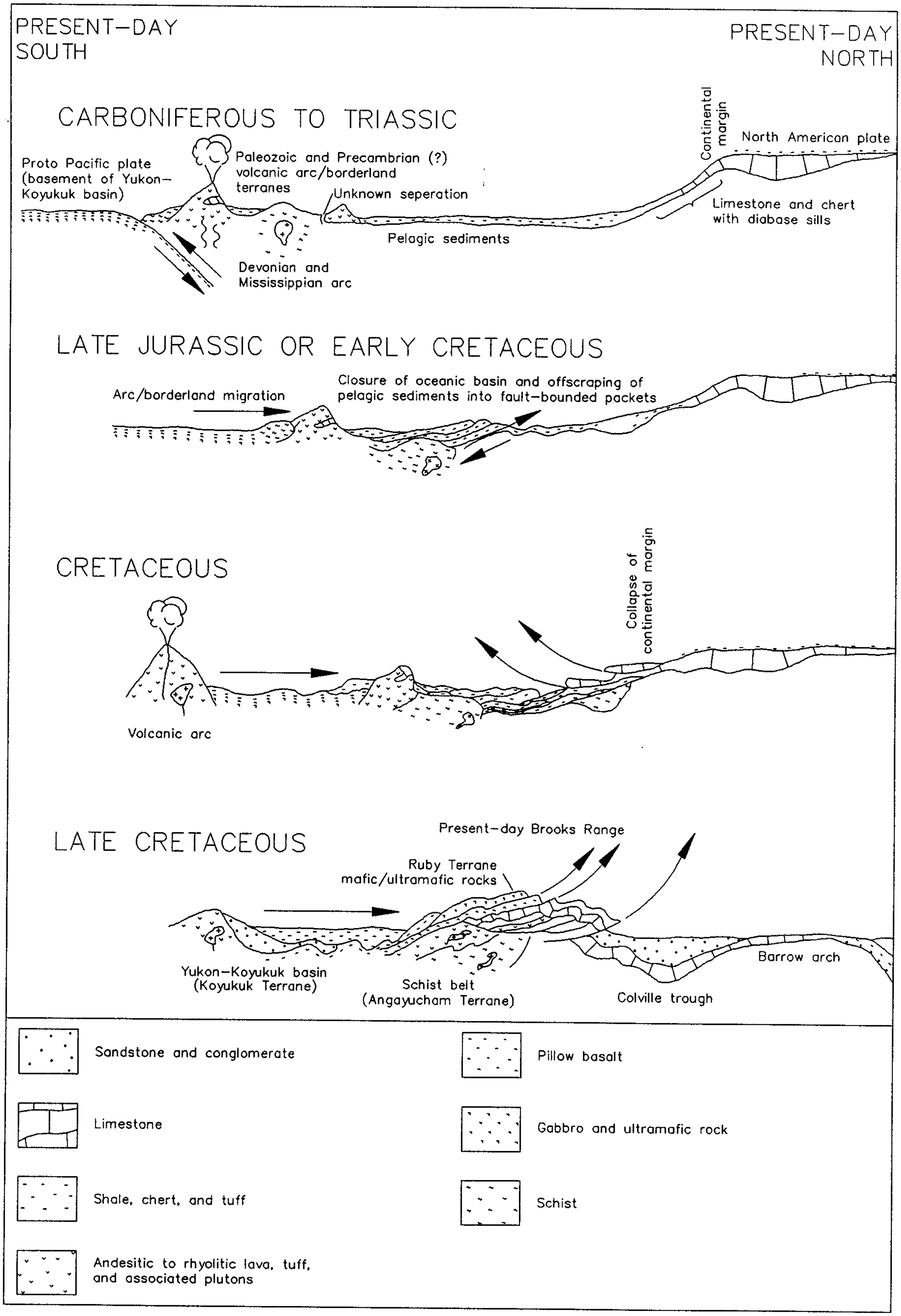


Figure 8. A series of sketches showing the structure and relationships between the Koyukuk, Angayucham, and Ruby terranes (after Churkin, Nokleberg, and Huie, 1979).

Ruby Terrane

The basement rocks of the Ruby terrane collected in a marine environment and consisted of marine sedimentary and mafic volcanic rocks (Turner, Forbes, and Dillon, 1979) of Precambrian (older than 570 Ma) age. These rocks underwent regional metamorphism to the blueschist facies in Late Precambrian time (2,500 to 570 Ma). Precambrian subduction may have caused this metamorphism (Turner, Forbes, and Dillon, 1979).

Marine sedimentation continued into the Paleozoic (570 to 245 Ma), with limestone deposition from the Middle Devonian through the Early Mississippian (387 to 352 Ma) (Smith et al., 1978). Turner, Forbes, and Dillon (1979), suggest that carbonate deposition may have begun as early as the Silurian (438 to 408 Ma). Middle Devonian (387 to 374 Ma) granitic plutons and hypabyssal felsic rocks intruded these carbonate rocks and the underlying metamorphic rocks. Related felsic volcanism and carbonate deposition occurred at this time and formed a laterally extensive Devonian volcanogenic sequence in an ensialic island arc or a magmatic belt on a submerged continental margin (Dillon, Pessel et al., 1980). Volcanogenic stratiform sulfide deposition occurred in this sequence in Middle to Late Devonian time (387 to 360 Ma) (Hitzman et al., 1983). The Late Devonian, a period of carbonate deposition on the horsts and deep water sedimentation and bimodal volcanism in the intervening grabens, was associated with a rifted continental margin (Hitzman et al., 1983). Deposition of marine sediments may have continued into the Triassic (245 to 208 Ma) (Box, 1985).

The rocks of the Angayucham terrane were thrust over the rocks of the Ruby terrane in Jurassic and Early Cretaceous time (208 to 97.5 Ma). This compressive tectonic event caused intense deformation and greenschist facies metamorphism in the rocks of the Ruby terrane (Churkin, Nokleberg et al., 1979; Turner, Forbes, Dillon, 1979).

Angayucham Terrane

The Ruby terrane faced an area of open ocean to the west and to the south in Devonian time (408 to 360 Ma). Deep water marine sediments collected on an oceanic crust in this area of open ocean (Roeder and Mull, 1978). A series of sea floor basalts erupted onto the Devonian sediments in Mississippian through Triassic time (360 to 208 Ma). An incomplete ophiolite sequence, including mafic and ultramafic cumulates and remnants of a sheeted dike complex, was thrust over the Mississippian through Triassic pillow basalts in Mesozoic time (245 to 66.4 Ma), probably in Late Triassic or Early Jurassic time (230 to 187 Ma). These Devonian through Triassic sediments and basalts, with the structurally overlying ophiolite sequence, form the Angayucham terrane. This terrane was thrust over the Ruby terrane rocks in Jurassic and Early Cretaceous time (208 to 97.5 Ma).

Koyukuk Terrane

Three different theories can explain the formation of the Koyukuk terrane. The first two theories involve rifting followed by compression, while the third has only a compressive phase.

Theory 1 - Gemuts et al., 1983 (figure 9)

The area of the Koyukuk terrane was an area of possibly submerged, Precambrian and early Paleozoic (older than 438 Ma), continental crust in Early and pre-Devonian time (before 387 Ma). Rifting began, during Devonian time (408 to 360 Ma), along the present-day Kobuk fault zone and along a zone running from the eastern end of the Kobuk fault zone to the southwest. The chert, mafic volcanic and volcaniclasitc rocks, and associated mafic and ultramafic intrusive rocks of the Angayucham terrane formed in these rifts. Rifting continued into Triassic time (245 to 208 Ma).

Beginning in the Jurassic and continuing into the Early Cretaceous (208 to 97.5 Ma), a compressional event forced the rifted continental wedge back into what was, essentially, its original position, and thrust the oceanic crust over the surrounding continental rocks (Ruby terrane). The rifted wedge of continental crust forms the Koyukuk terrane.

The Nimiuk Point No. 1 well, approximately 15 miles southeast of Kotzebue, contains apparent continental crust from about 5,960 feet to its total depth at 6,311 feet. These are metamorphic rocks that appear similar in nature to the rocks of the Ruby terrane. Gemuts et al. (1983) report upper amphibolite grade metamorphic rocks in the Selawik Hills and interpret them as continental basement in support of the above theory.

Theory 2 - Patton, 1975; Cavalero, 1983 (figure 10)

Prior to the Early Devonian (older than 401 Ma), continental crust existed in the present-day location of the Koyukuk Terrane. Early Devonian (401 to 387 Ma) rifting formed an ocean basin in the location of the present-day Koyukuk terrane. Rifting pushed the continental crust occupying that location to the south. Felsic-arc volcanism, along the continental margin to the north, accompanied rifting. A basaltic, oceanic arc formed to the south in Middle to Late Devonian time (387 to 360 Ma).

This ocean basin began to close in Triassic or Early Jurassic time (245 to 187 Ma). The oceanic arc collided with the continental margin, and the oceanic rocks of the Angayucham terrane were thrust over the continental rocks to the north (Ruby terrane) in Jurassic or Early Cretaceous time (163 to 97.5 Ma). The oceanic arc sequence of sediments form the Koyukuk terrane.

The types of volcanism and sedimentation associated with the area appear similar to that associated with ongoing arc-continent collision in eastern

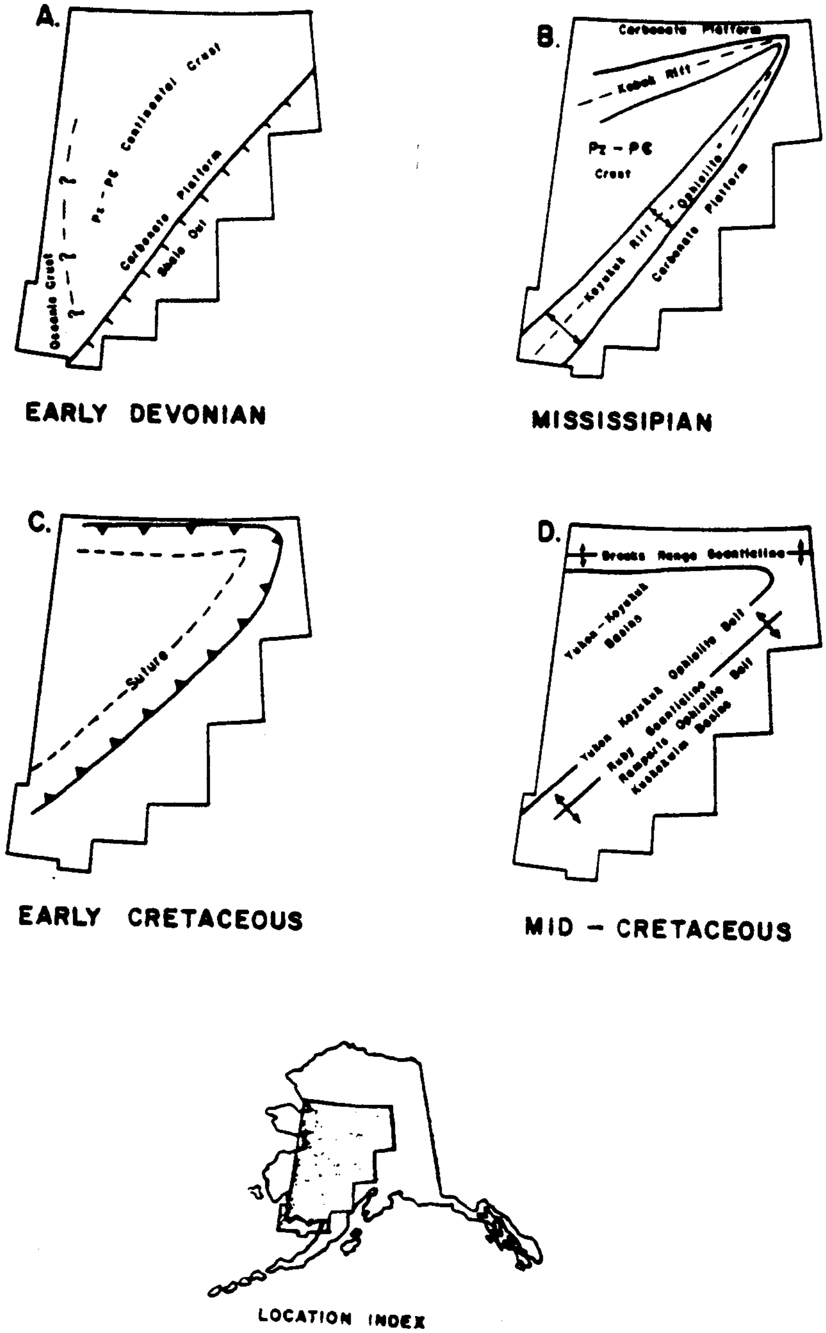


Figure 9. Pictographic representation of theory number 1 of the history of the Koyukuk Terrane (after Gemuts et al., 1973).

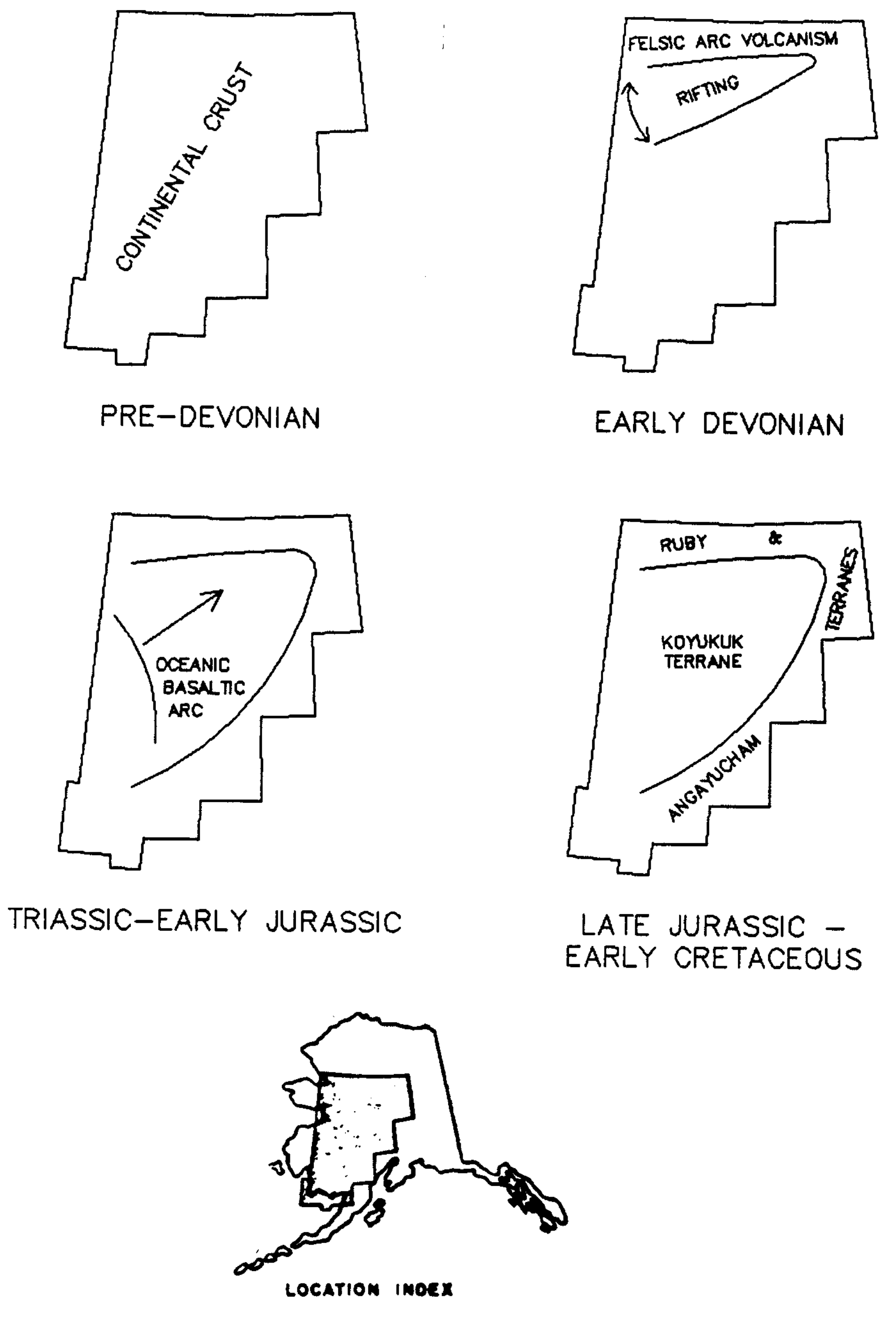


Figure 10. Pictographic representation of theory number 2 of the history of the Koyukuk terrane.

Taiwan (Box et al., 1985). Patton (1973) indicates that the rocks of the Angayucham terrane dip beneath the rocks of the Koyukuk terrane. The geochemistry of the granitic plutons in the Koyukuk terrane indicates that oceanic crust may underlie the YKP (Arth et al., 1984). Isotopic and gravity (figure 11) data indicate that the continental rocks do not extend under the YKP (Patton and Box, 1985). Some of the evidence presented here for theory 2 directly conflicts with theory 1.

Theory 3 - Box 1985; Box and Patton, 1985 (figure 12)

Prior to Cretaceous time (more than 144 Ma), the area of the present-day Koyukuk terrane was an ocean basin with continental crust to the north and southeast, and an oceanic arc to the southwest. The oceanic arc collided with the continental margin and fitted itself to the shape of the margin in Early Cretaceous time (144 to 97.5 Ma). Oceanic crust (Angayucham terrane) was thrust over the continental margin (Ruby terrane) during the collision. The oceanic arc volcanics and volcaniclastic sediments form the Koyukuk terrane. The continental crust of the Seward Peninsula rotated around the western side of the Koyukuk terrane and implaced in its present position in Late Cretaceous time (97.5 to 66.4 Ma).

All of the evidence for theory 2 also applies to theory 3. Patton, one of the originators of theory 2, has now accepted theory 3 (Box and Patton, 1985).

The area of Koyukuk NWR was essentially unglaciated during the Quaternary (younger than 1.6 Ma) periods of glacial advance that covered much of North America (Pewe, 1975). The only glaciation in the refuge occurred in the Zane Hills on the northern border of the refuge.

GEOCHEMISTRY

No available petroleum geochemistry data exists from within Koyukuk NWR. Geochemical analyses were performed on cutting and/or core samples from the Paul G. Benedum Nulato Unit No. 1 (figure 13, table 1) and from the Standard Oil of California Nimiuk Point No. 1 (figure 14, table 2). Geochemical analyses were also run on surface samples from the Waring Mountains in Selawik NWR (figure 15, table 3), and from the coast along the east side of Norton Sound (figure 16, table 4). All of these locations are within the Yukon-Koyukuk province.

The geochemical analyses of all pre-Tertiary (older than 66.4 Ma) samples from the above locations indicates that they are gas prone and overmature for oil or wet gas generation; however, they may retain some dry gas. The Nulato well is too mature below 750 feet to retain any dry gas. The Tertiary sediments in the Nimiuk Point well are gas prone and immature. The Tertiary sediments in sample 44-GB-78 from the coast of Norton Bay are mature for oil generation, but are gas prone.

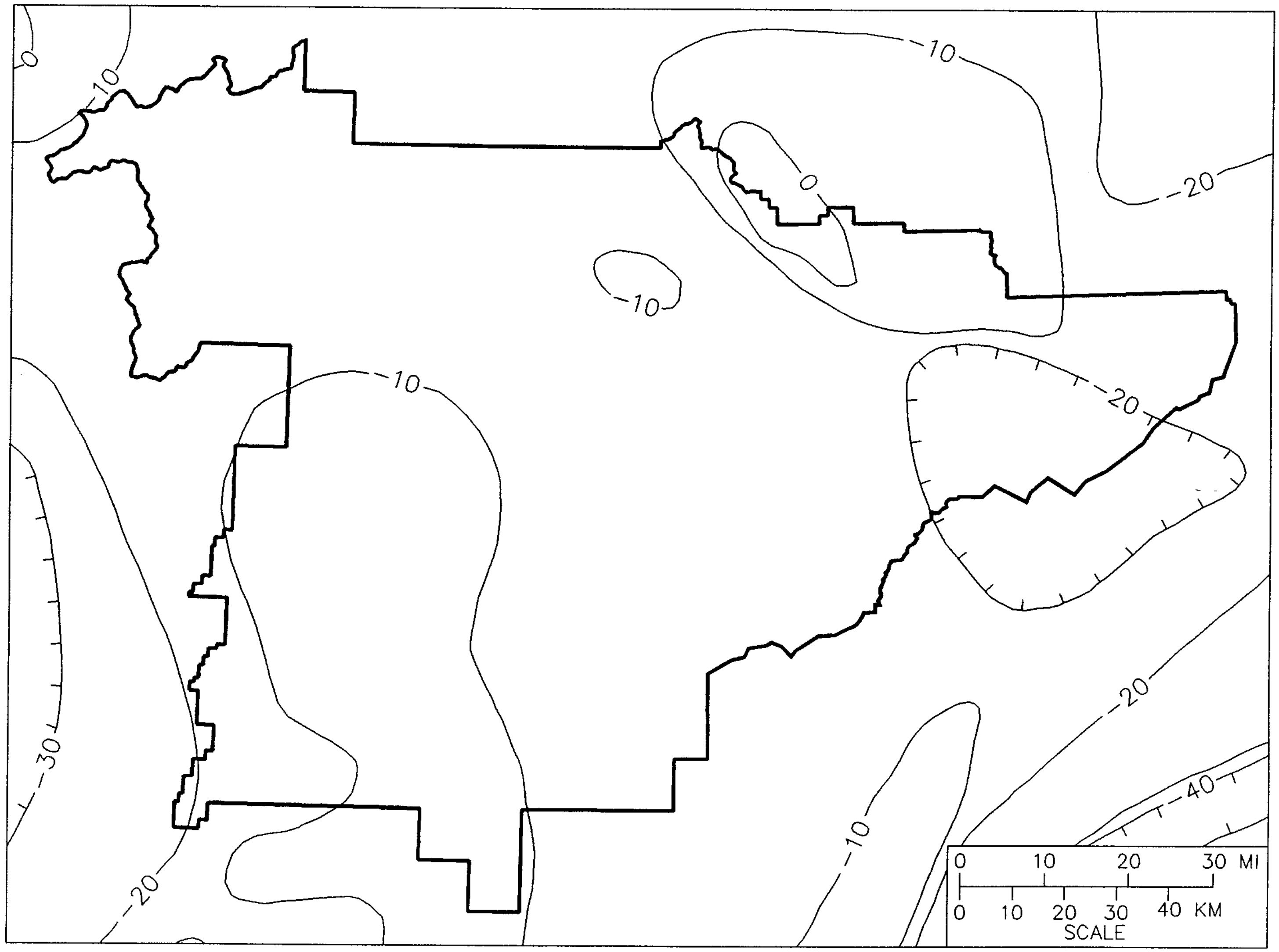


Figure 11. Bouguer gravity map of Koyukuk NWR (from Barnes, 1977).
(contour interval = 10 milligals)

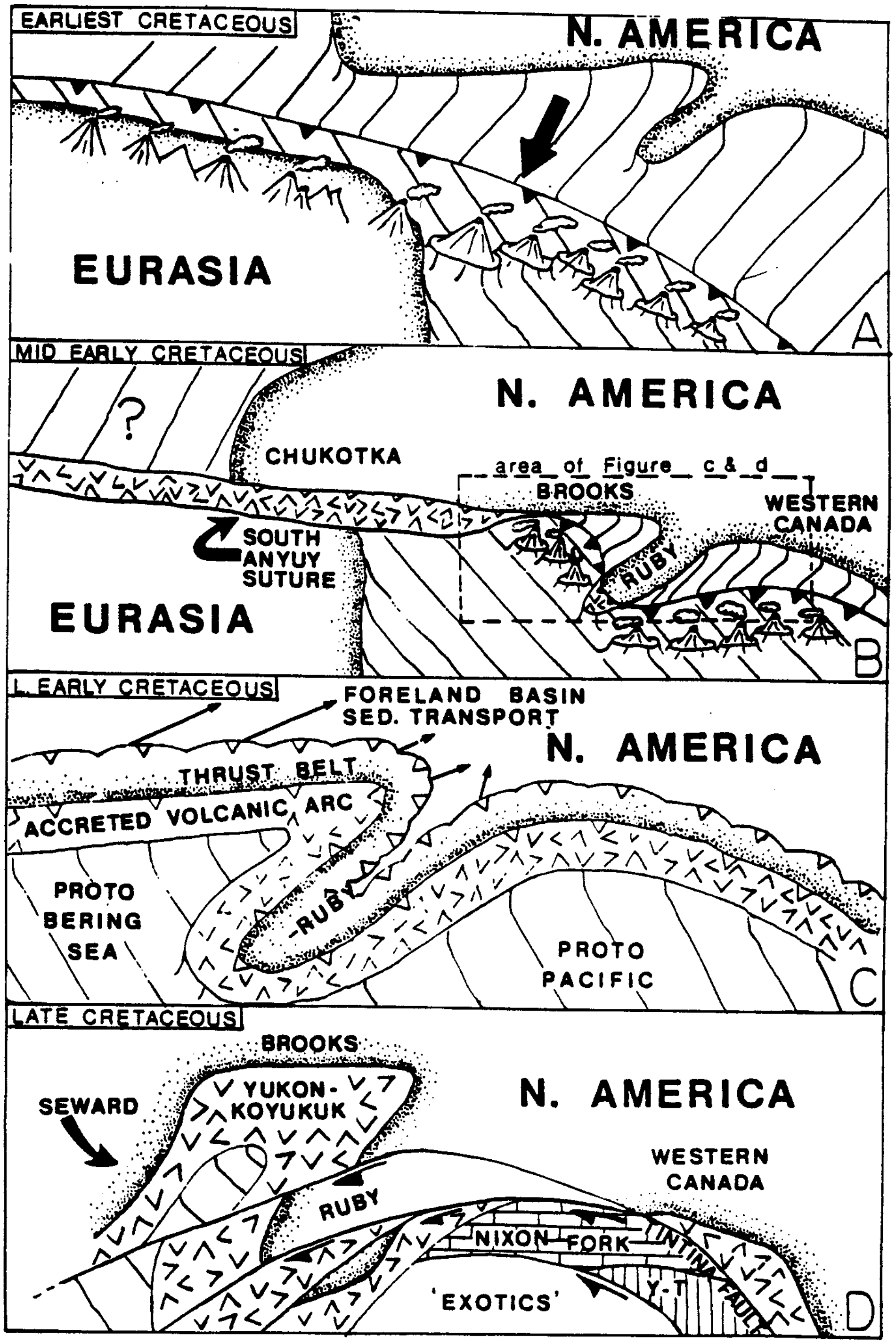


Figure 12. Pictographic representation of theory number 3 of the history of the Koyukuk terrane (from Box, 1985).

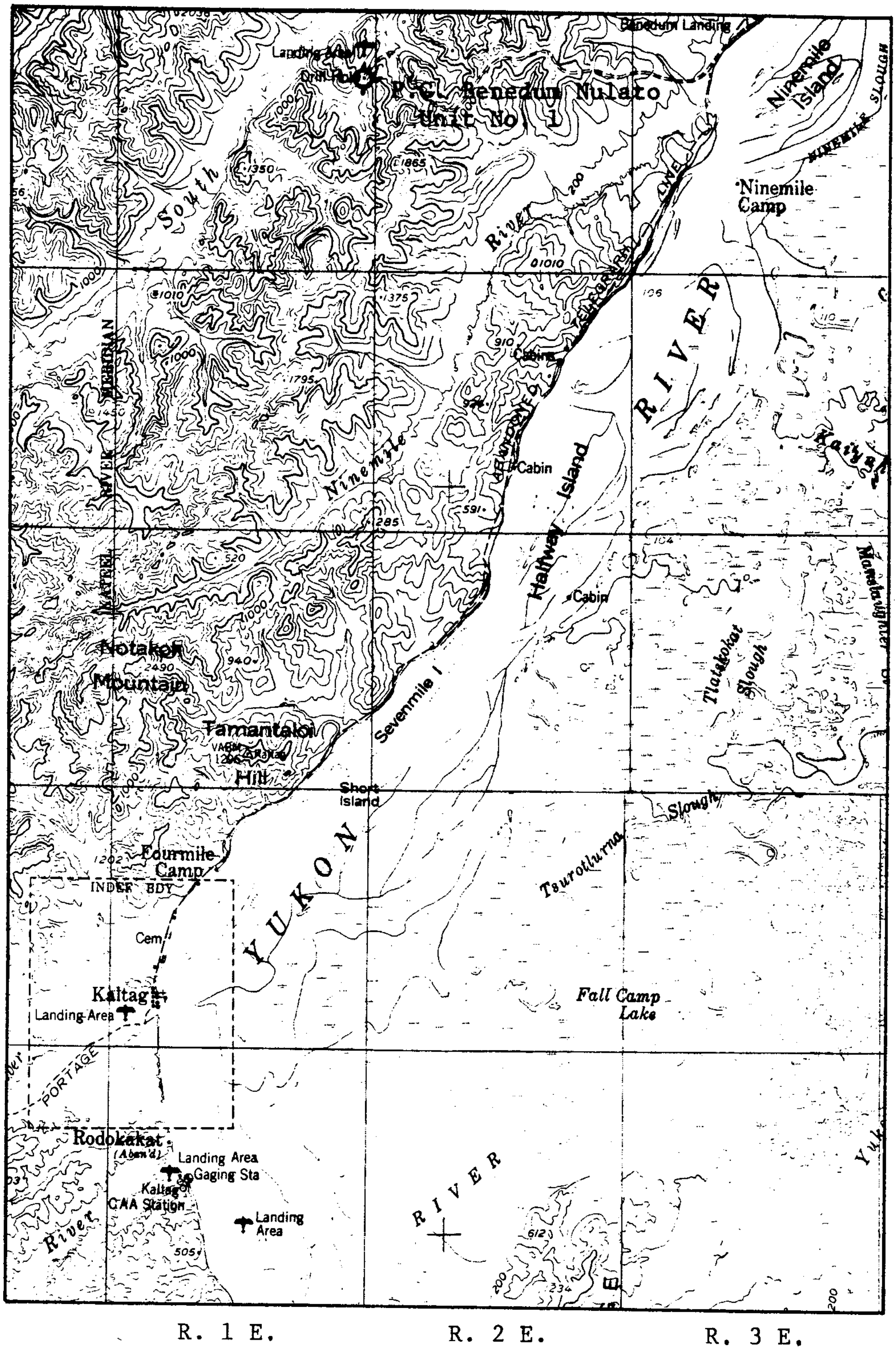


Figure 13. Location map for the P.G. Benedum Nulato Unit No. 1 well.

Table 1

Thermal Maturation and Visual Kerogen Analyses
Benedum Nulato Unit No. 1
(available for inspection at the Geologic Materials Center*)

DEPTH/ REMARKS	LOW-GRAY Ro MEAN	% POP	HIGH-GRAY Ro MEAN	% POP	TAI	THERMAL MATURITY	KEROGEN TYPE	HYDROCARBON POTENTIAL/REMARKS
50'	2.62	62	----	---	---	Overmature	Cellulosic	Gas type kerogen
400'	2.70	92	----	---	---	Overmature	Cellulosic	Gas type kerogen
750'	3.28	91	4.07	8	---	Overmature	Cellulosic	Gas type kerogen
1100'	3.21	82	3.97	13	---	Overmature	Cellulosic	Gas type kerogen
1450'	3.18	94	4.34	1	---	Overmature	Cellulosic	Gas type kerogen
1800'	3.27	72	4.12	16	---	Overmature	Cellulosic	Gas type kerogen
2150'	3.44	80	4.21	16	---	Overmature	Cellulosic	Gas type kerogen
2500'	3.38	84	4.52	7	---	Overmature	Cellulosic	Gas type kerogen
2900'	3.45	92	4.82	5	---	Overmature	Cellulosic	Gas type kerogen
3300'	3.62	76	4.59	20	---	Overmature	Cellulosic	Gas type kerogen
3700'	3.77	72	4.59	22	---	Overmature	Cellulosic	Gas type kerogen
4100'	3.61	92	----	--	---	Overmature	Cellulosic	Gas type kerogen
4900'	4.07	93	5.45	3	---	Overmature	Cellulosic	Gas type kerogen
5300'	3.91	74	5.04	6	---	Overmature	Cellulosic	Gas type kerogen
5700'	3.91	92	5.52	5	---	Overmature	Cellulosic	Gas type kerogen
6100'	4.10	83	5.63	12	---	Overmature	Cellulosic	Gas type kerogen

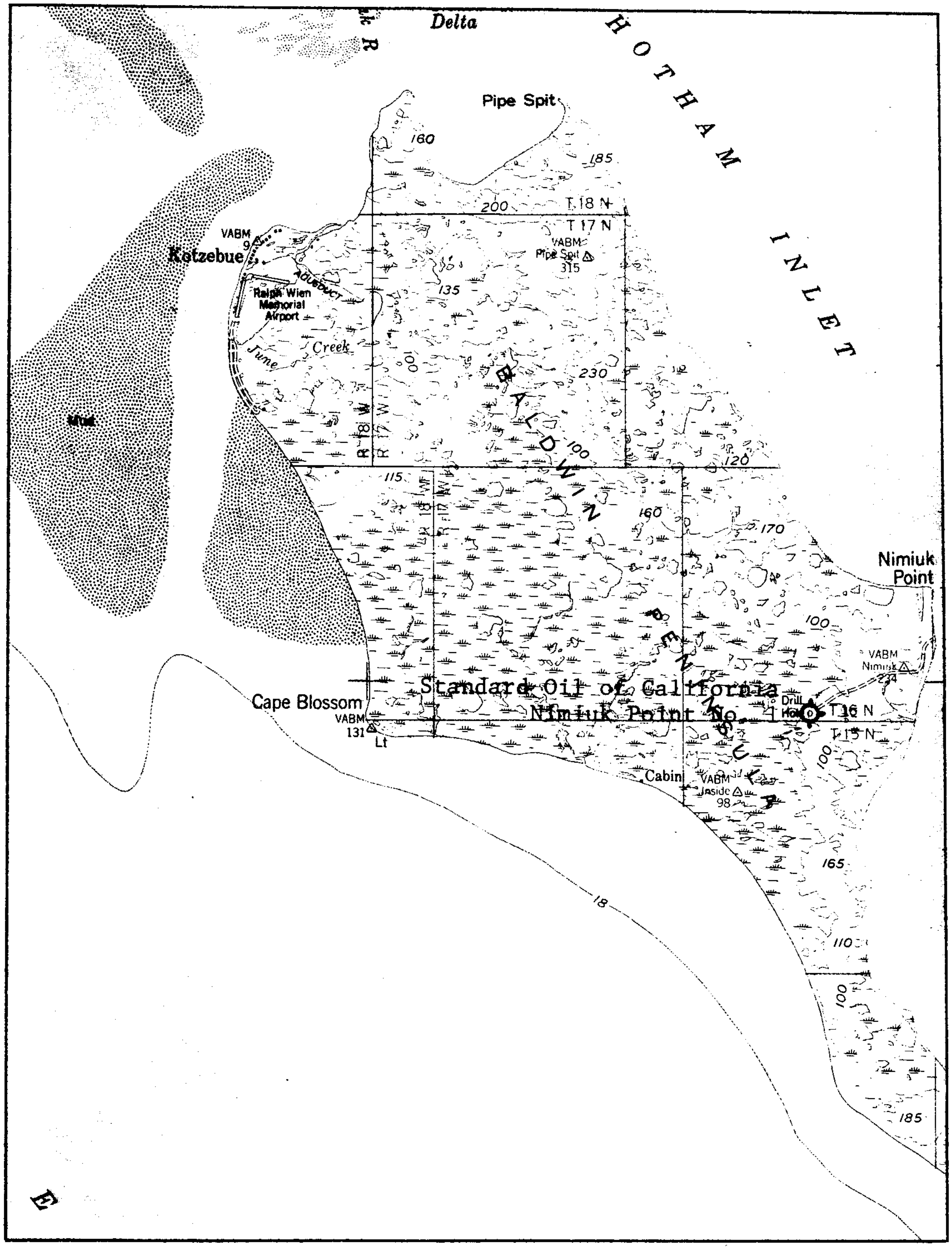


Figure 14. Location map for the Standard Oil of California Nimiuk Point No. 1 well.

Table 2

Thermal Maturation and Visual Kerogen Analyses
Standard Oil of California Nimiuk Pt. No. 1, (Anonymous, 1986c)

DEPTH	LOW-GRAY Ro MEAN	% POP	HIGH-GRAY Ro MEAN	% POP	TAI	THERMAL MATURITY	KEROGEN TYPE	HYDROCARBON POTENTIAL/REMARKS
100'	0.19	18	0.36	37		Immature	Cellulosic	Gas type kerogen
460'	0.23	65	0.69	33		Immature	Cellulosic	Gas type kerogen
820'	0.25	85	1.64	15		Immature	Cellulosic	Gas type kerogen
1180'	0.28	36	0.58	37	2	Immature	Cellulosic	Gas type kerogen
1540'	0.25	69	0.99	31	2	Immature	Cellulosic	Gas type kerogen
1900'	0.25	74	1.10	26	1+	Immature	Cellulosic	Gas type kerogen
2260'	0.34	85	1.75	15		Immature	Cellulosic	Gas type kerogen
2530'	0.35	80	0.91	20		Immature	Cellulosic	Gas type kerogen
2890'	0.31	74	2.29	17		Immature	Cellulosic	Gas type kerogen
3250'	0.37	66	0.72	34		Immature	Cellulosic	Gas type kerogen
3650'	0.35	100	-	-		Immature	Cellulosic	Gas type kerogen
3970'	0.39	45	0.59	32		Immature	Cellulosic	Gas type kerogen
4330'	0.36	100	-	-		Immature	Cellulosic	Gas type kerogen
4690'	0.37	72	1.36	25		Immature	Cellulosic	Gas type kerogen
5050'	0.41	47	0.74	38		Immature	Cellulosic	Gas type kerogen
5410'	0.44	85	0.87	15	2	Immature	Cellulosic	Gas type kerogen
5770'	0.51	68	1.03	32	2,2+	Immature	Cellulosic	Gas type kerogen
6130'	-	-	-	-	-	-		Metamorphic rocks
6250'	-	-	-	-	-	-		Metamorphic rocks

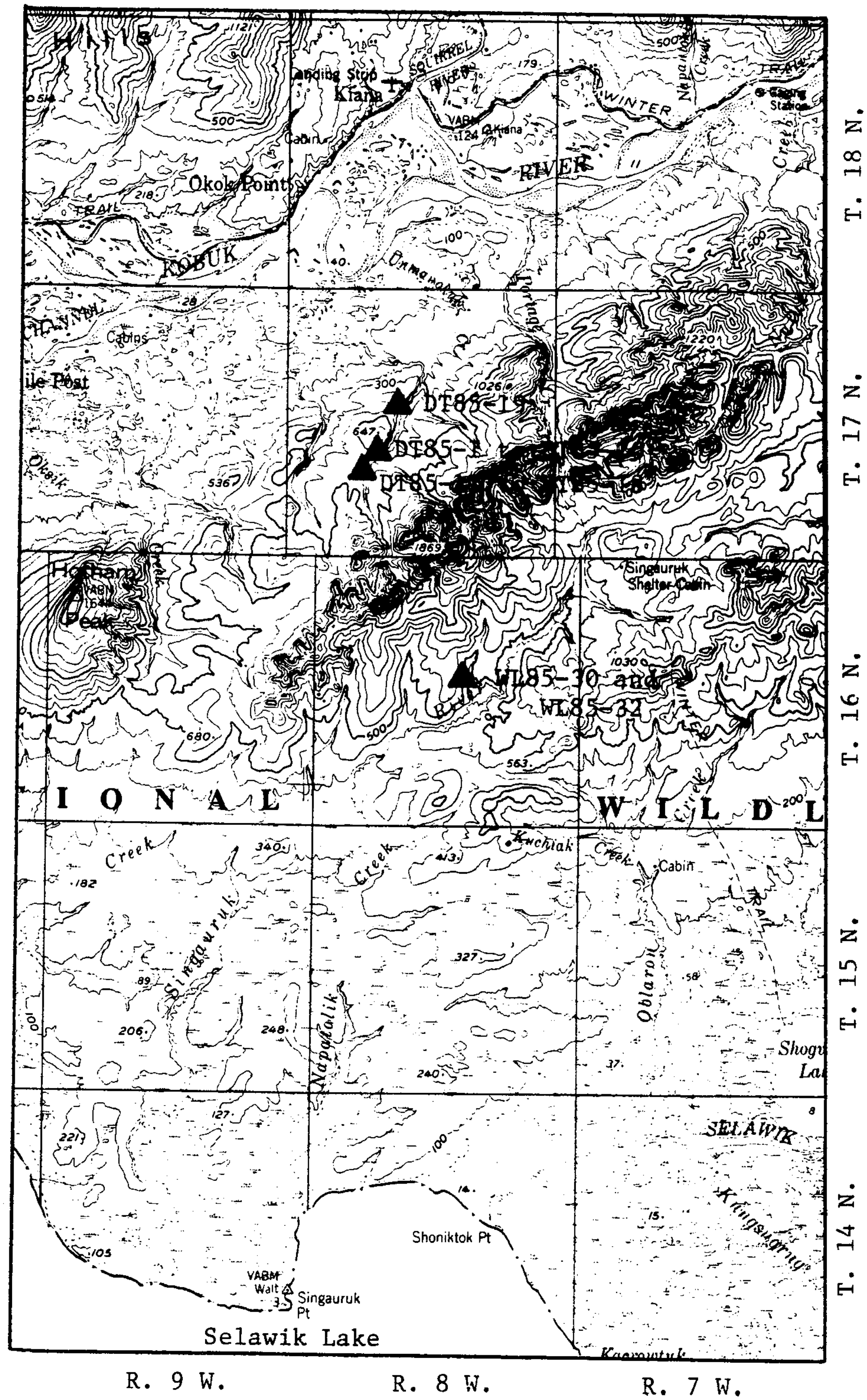


Figure 15. Map of sample locations in the Waring Mountains.

Table 3

Thermal alteration index (TAI), total petroleum hydrocarbons (TPH) and equivalent vitrinite reflectance (EVF) data for Cretaceous rocks from the Waring Mountains (Anonymous, 1986c).

SAMPLE NO.	TPH (PERCENT)	TAI	EVF (PERCENT)
WL85-30	.00041		
WL85-32	.00190		
DT85-1	.00320		
DT85-2		3+ TO 4-	2.0 TO 2.5
DT85-3	.00140		
DT85-4			
DT85-5	.00030		
DT85-6		3+	2.0
DT85-7	.00014		
DT85-8		3+ TO 4-	2.0 TO 2.5
DT85-9	.00190		
DT85-10		3+ TO 4-	2.0 TO 2.5
DT85-11	.00160		
DT85-12		3+	2.0
DT85-13	.00170		
DT85-14		3+ TO 4-	2.0 TO 2.5
DT85-15	.00140		
DT85-16		3+ TO 4-	2.0 TO 2.5
DT85-17	.00160		
DT85-18		3+ TO 4-	2.0 TO 2.5
DT85-19		3+ TO 4-	2.0 TO 2.5

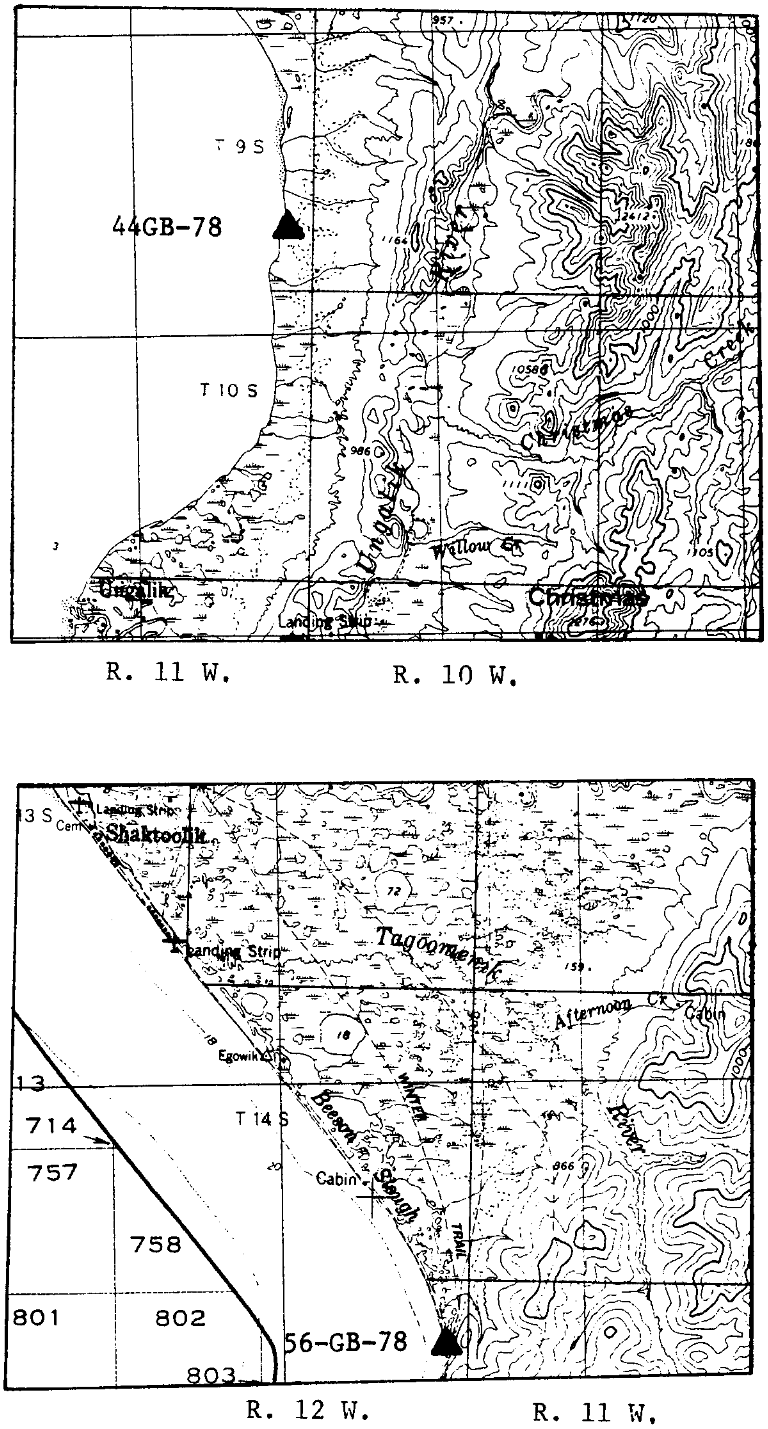


Figure 16. Map of sample locations on the coast of Norton Bay.

Table 4

Organic Carbon Content (TOC) and Thermal Alteration Index (TAI) for Samples from the Coast of Norton Sound (Lyle et al., 1982)

Sample No.	TOC (%)	TAI
44-GB-78	0.41	2- to 2
56-GB-78	4.30	3+

The geochemistry of the pre-Tertiary sediments in the YKP indicates that they have no significant oil or gas generation potential. If they had generated oil or gas in the past, it would have been either driven off or degraded to, at best, dry gas.

There is no petroleum geochemistry data for Tertiary sediments anywhere in the YKP equivalent to the Tertiary sediments within the refuge. Aeromagnetic surveys indicate volcanic and/or intrusive rocks at shallow depths under the Tertiary sediments of Koyukuk Flats (Gates, et al., 1968). If these sediments are as thin as indicated, none of them would be thick enough for oil or gas generation to occur even if the proper kerogens were present.

DESCRIPTION OF OIL AND GAS RESOURCES

Known Oil and Gas Fields (Regional)

Alaska has two areas that produce oil and/or gas. These areas are the Cook Inlet Basin and the arctic North Slope. The Katalla field, on the coast of the Gulf of Alaska, produced oil until the 1930s. None of these areas are related to the Koyukuk NWR and are, therefore, not discussed.

Known Oil and Gas Fields (Local)

Koyukuk NWR and the surrounding area contain no known oil or gas fields.

A prospector reported three oil seeps in the vicinity of Allakatet on the Koyukuk River. The U.S. Geological Survey has been unable to confirm the presence of these seeps (Miller, Payne, and Gryc, 1959).

Paul G. Benedum drilled the Nulato Unit Well No. 1 (SE 1/4, Sec. 12, T. 10 S., R. 1 E., Kateel River Meridian) fifteen miles southwest of Nulato and about 26 miles south of the refuge between November 29, 1959, and June 24, 1960. The well reached a total depth of 12,015 feet and had no indications of oil or gas. The well history (available for inspection at the Alaska Oil and Gas Conservation Commission) states "proximity to an active oil seep" as one reason for locating the well at that position. The U.S. Geological Survey has been unable to confirm the presence of this seep (Patton, 1988, personal communication).

Standard Oil Company of California drilled the Nimiuk Point Number 1 well (Sec. 34, T. 16 N., R. 16 W., Kateel River Meridian) seventeen miles southeast of Kotzebue and about 110 miles west-northwest of the refuge to a depth of 6,311 feet in 1974. They plugged and abandoned it in 1975 as a dry hole. There was no indication of oil in the well. A formation test, run at 3,537 to 3,55 feet, resulted in a short blow, but no gas was observed at the surface; therefore, this test must be classified as inconclusive. Geophysical well logs indicate that gas may be present from 1,130 to 1,132 feet and from 1,158 to 1,160 feet. These zones are too thin to hold large quantities of gas, if they in fact do contain gas.

OIL AND GAS POTENTIAL

Oil and Gas Occurrence Potential

Koyukuk NWR has a low oil and/or gas (hydrocarbon) occurrence potential (figure 17), BLM classification of L/A (Appendix B). The possible occurrence of dry gas in the pre-Tertiary (older than 66.4 Ma) sediments at other areas of the YKP outside of the refuge indicate that the refuge has a low hydrocarbon occurrence potential. The lack of data from within the refuge and the uncertainty of the projections result in the low level of certainty given to the classification.

Typical Oil and Gas Development Scenario

The Koyukuk NWR has a low hydrocarbon occurrence potential with a low level of certainty. Therefore, the scenario presented below is very generalized.

Any potential development would most likely be a small gas deposit which would be produced for local needs. To be economic, the prospect must be located near the gas market. Disturbance in the area would be minimal: one or two gas wells, separator facility, road from the field to existing infrastructure, and a parallel, small-diameter pipeline. A small office would be located on-site, but there would not be any housing modules. An estimate of the area disturbed by the above development would range from 10 to 20 acres and would require approximately 120,000 cubic yards of gravel (assuming gravel pads and roads would be five feet thick to protect the permafrost environment).

Oil development in the Koyukuk NWR is very unlikely. A large oil deposit would have to be discovered to justify the expense of producing and transporting the product to a viable market. The low potential classification for this area indicates that discovery of such a deposit is unlikely.

If a larger gas deposit is discovered, the development would be on a larger scale and could be located farther from the gas market. Assuming these parameters, one could expect a development scenario very similar to the scenario presented in the Selawik National Wildlife Refuge Oil and Gas Assessment. Facilities needed for production would include gas wells, injection well, central production facility, small airstrip, housing and office modules, pipelines, and roads. Total acreage disturbed would range from 30 to 60 acres and would require approximately 250,000-500,000 cubic yards of gravel.

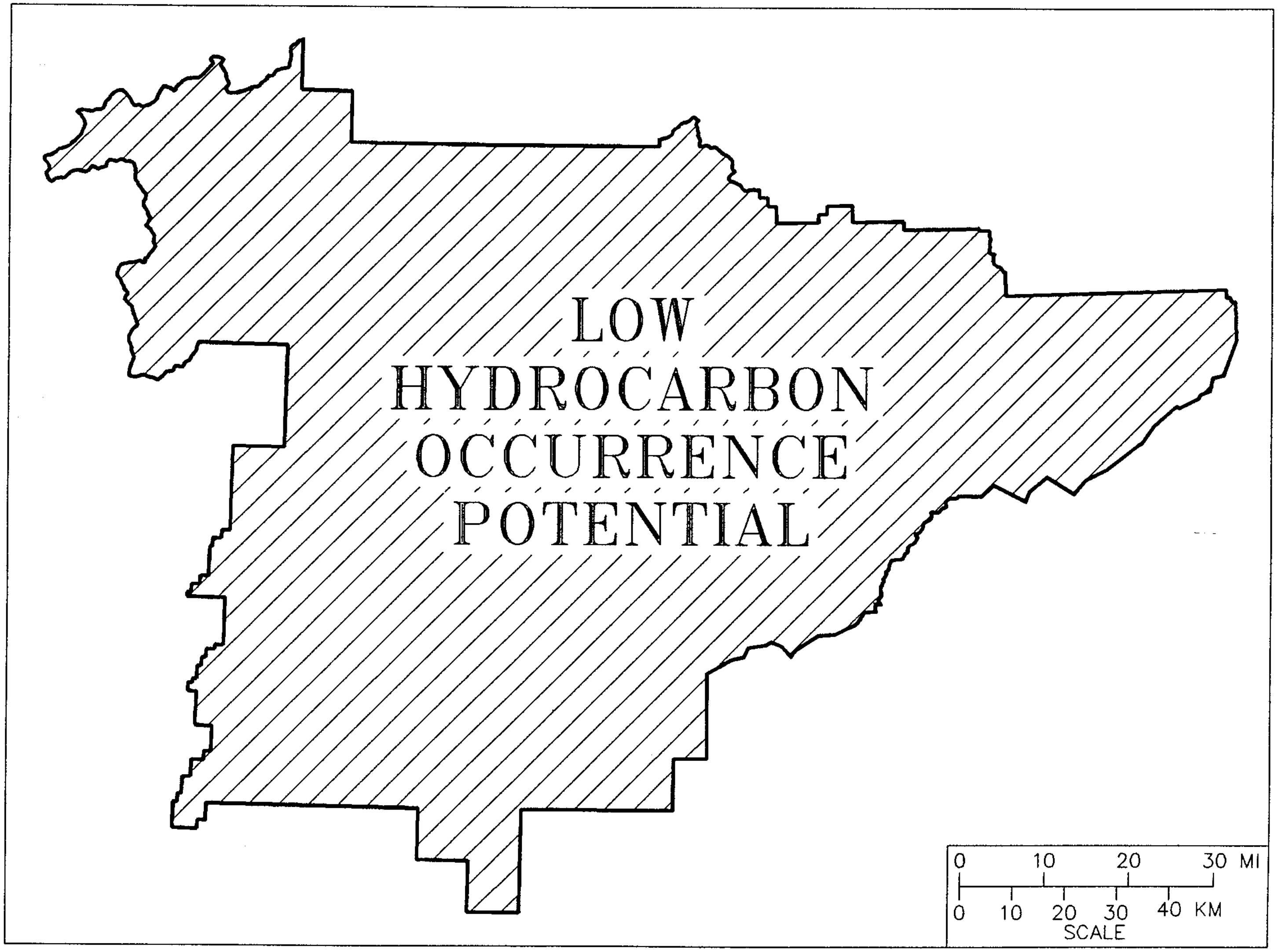


Figure 17. Hydrocarbon occurrence potential map of Koyukuk NWR. The entire refuge has a low hydrocarbon occurrence potential (BLM mineral potential classification of L/A).

Economic Potential

Based on geology and the subsequent low hydrocarbon occurrence potential, the whole of the Koyukuk NWR has been determined to have no economic potential for the development of oil and gas resources through the next quarter of a century (figure 18).

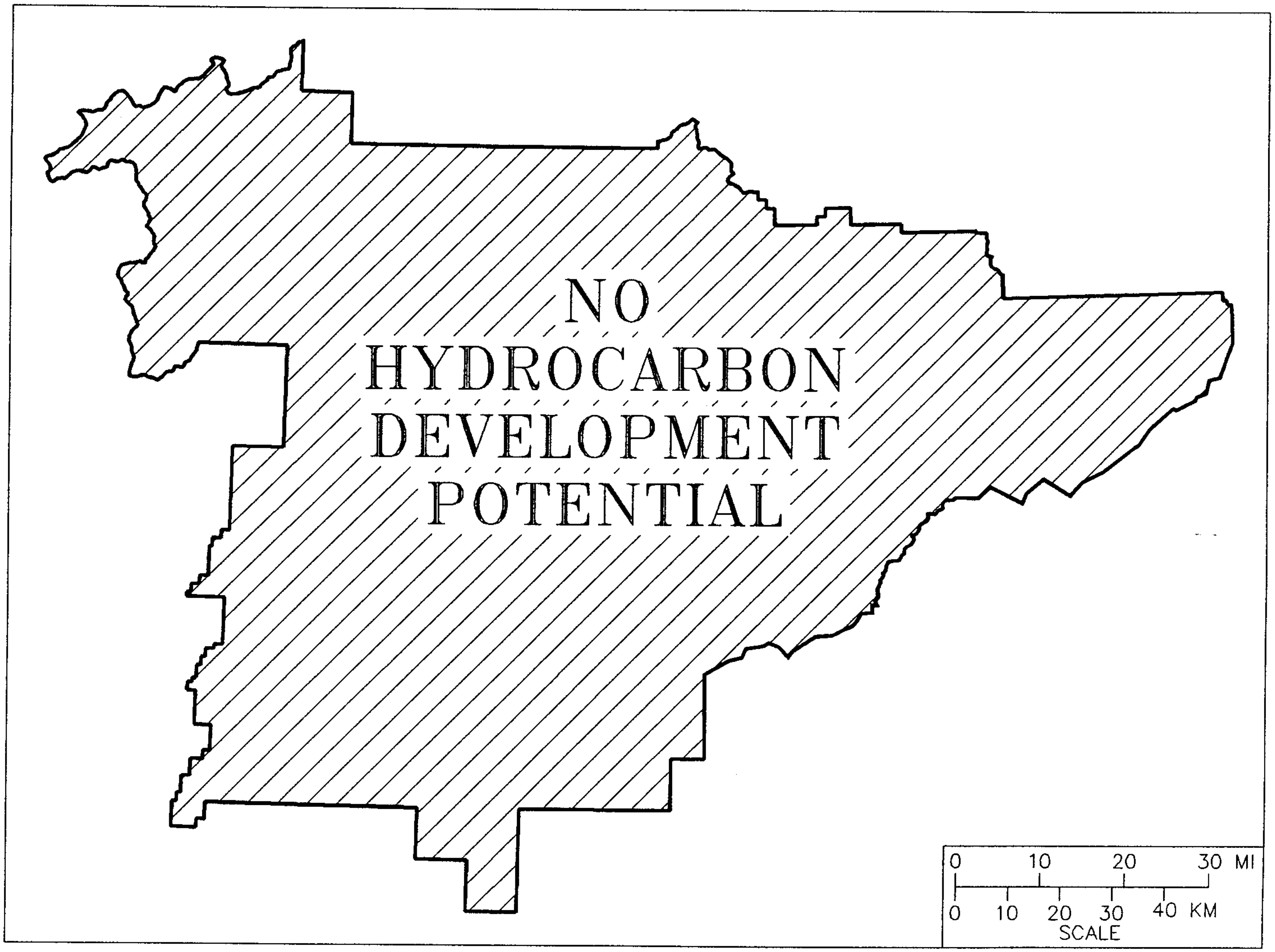


Figure 18. Hydrocarbon development potential map of Koyukuk NWR.

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APPENDIX A

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
FISH AND WILDLIFE SERVICE
AND THE
BUREAU OF LAND MANAGEMENT
U.S. DEPARTMENT OF THE INTERIOR

BACKGROUND:

Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA) requires the Secretary of the Interior to initiate an oil and gas leasing program on the Federal lands of Alaska; it exempts, ". . . those units of the National Wildlife Refuge System where the Secretary determines, after having considered the national interest in producing oil and gas, would be incompatible with the purpose for which such unit was established." Section 1008 also mandates that:

> "In such areas as the Secretary deems favorable for the discovery of oil or gas, he shall conduct a study, or studies, or collect and analyze information obtained by permittees authorized to conduct studies under this section, of the oil and gas potential of such lands and those environmental characteristics and wildlife resources which would be affected by the exploration for and development of such oil and gas."

Section 304(g) of ANILCA requires that the Secretary of the Interior prepare a "comprehensive conservation plan" for each of the 16 National Wildlife Refuges in the State of Alaska. Among other things, these plans are to, ". . . specify the uses within each such area which may be compatible with the major purposes of the refuge." The U.S. Fish and Wildlife Service (FWS) has the responsibility for preparing the refuge comprehensive conservation plans and is using the refuge planning process to define those areas on refuges where oil and gas exploration and development may be compatible with the purposes for which each refuge was established.

PURPOSE:

To fully comply with Section 1008 of ANILCA (i.e., to consider the national interest in producing oil and gas from refuge lands) an accurate defensible oil and gas resource assessment should be prepared for each national wildlife refuge in Alaska. The FWS has limited technical expertise in assessing mineral potentials. However, this expertise does exist within the U.S. Bureau of Land Management (BLM). The purpose of this memorandum is to establish cooperative procedures between the FWS and the BLM for the mutual responsibility of assessing the oil and gas potential of national wildlife refuge lands in Alaska.

IT IS MUTUALLY AGREED THAT:

The BLM will develop an oil and gas resource assessment for each of the 16 national wildlife refuges in the State of Alaska. These assessments will consist of the following items (to the extent that available data permits):

1. A detailed narrative discussion of the geologic character of the refuge.

2. A map showing all known geologic formations and geologic features pertinent to the mineral assessment.

3. A geologic cross section showing the sub-surface character of the study area.

4. A detailed discussion of the engineering aspects, if there is a potential for development in the area, including the types of facilities and the infrastructure necessary to economically develop the hydrocarbon potential.

5. A generic development scenario map that will graphically portray the facilities and infrastructure discussed in item 4 above.

6. An economic assessment that will include:

   a. a brief overview of the national energy situation and discussion of the importance of Alaskan oil and gas production.
   b. a generalized discussion of the economic potential for oil and gas production from the refuge being evaluated.
   c. a discussion of the factors that may affect future oil and gas development on the refuge.

The above six items shall be considered the minimum elements to be included in any refuge assessment. If sufficient nonproprietary geological and geophysical data exist, and the hydrocarbon resources warrant further description, some or all of the following items (time permitting) will also be included in the resource assessment:

   a. structural contour maps showing the location and surface areas of potential mineral occurrences,
   b. maps showing the magnetic and/or gravity character of the area,
   c. maps showing the thickness of identified rock formations,
   d. reservoir character map showing the porosity, water saturation, and permeability characteristics of potential reservoirs, and
   e. a detailed development scenario map showing roads, docks, pipeline corridors, etc., required to develop the prospects.

In preparing the oil and gas resource assessments the BLM shall make use of 1) existing literature, 2) geological and geophysical information and data collected from FWS lands by industry permittees (see Memorandum of Understanding between FWS and BLM dated August 1984--attachment 1), and 3) geological and geophysical information and data collected on or adjacent to FWS lands by the BLM, the U.S. Geological Survey, the State of Alaska, and other government agencies. During the evaluation process, BLM geologists will make official contacts with mineral companies that may have an interest in the area. These companies will be given an opportunity to submit data for consideration and they will also be given the opportunity to discuss their feelings on the study area and its oil and gas development potential with the evaluating geologists. All interactions will be documented and submitted to the FWS at the close of the project.

The oil and gas resource assessments prepared by BLM will be delivered to the FWS in form suitable for public release. These assessments will be public documents, and the FWS will make copies of the assessments available for public review. All formal communications with the public concerning the management of FWS lands (e.g., the opening of refuge lands to oil and gas exploration or development) will be the responsibility of the FWS.

In developing the oil and gas assessment, proprietary information that was obtained by the BLM will be shared with the FWS as support for statements made in the assessment; however, proprietary information will not be included in the public report.

The number of refuge resource assessments that BLM will complete each year and the amount of funding that FWS will provide to BLM will be determined on an annual basis by mutual agreement. The following three goals have been established to assist the FWS and the BLM in planning their work commitment for completing the refuge oil and gas assessments:

1. The Becharof, Alaska Peninsula, Yukon Flats and Kenai National Wildlife Refuge oil and gas assessments will be completed during the 1986 Fiscal Year.

2. If at all possible, the oil and gas assessments for the remaining 12 refuges will be completed during the 1987 and 1988 Fiscal Years.

3. The FWS will reimburse the BLM for completion of oil and gas assessments and FWS will prioritize the assessments to be completed each year, with consideration for concurrently conduction analyses, if possible, on refuges in similar geographic location or of similar geologic character.

However, nothing in this MOU shall be construed as requiring either agency to assume or expend any funds in excess of appropriations available. The remaining 12 national wildlife refuge resource assessments will be conducted in the priority order established by the FWS on an annual basis:

1. Togiak NWR
2. Tetlin NWR
3. Kanuti NWR
4. Yukon Delta NWR
5. Koyukuk NWR
6. Nowitna NWR
7. Innoko NWR
8. Selawik NWR
9. Kodiak NWR
10. Alaska Maritime NWR
11. Izembek NWR
12. Arctic NWR

Amendments to this agreement may be proposed by either party and shall become effective upon mutual approval. Meetings to discuss the MOU may be called by the FWS Regional Director or the BLM State Director.

/s/ Robert E. Gilmore — 3/17/86
Regional Director — Date
U.S. Fish and Wildlife Service

/s/ Michael J. Penfold — 2-26-86
State Director — Date
Bureau of Land Management

Attachment 1

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
FISH AND WILDLIFE SERVICE
AND THE
BUREAU OF LAND MANAGEMENT
U.S. DEPARTMENT OF THE INTERIOR

ARTICLE 1 Background and objectives

Jointly the Fish and Wildlife Service (FWS) and the Bureau of Land Management (BLM) share responsibility to help meet Department of the Interior objectives in Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA) of December 1980. The FWS is authorized to issue permits for the study of oil and gas on national wildlife refuges; the BLM may analyze resulting data for identification of potential.

The FWS is issuing permits for surface geology on all refuges. Permits for geophysical exploration may be issued on refuges having approved comprehensive conservation plans. Data from both activities are required to be furnished to the FWS.

This Memorandum of Understanding is entered into to initiate the role of BLM to accept such data from FWS and be responsible for its confidentiality.

ARTICLE 2 Statement of work

The FWS agrees to deliver to BLM data collected from permittees of oil and gas studies provided for in Section 1008 of ANILCA. The BLM agrees to accept the data, store it, and keep it confidentiality.

ARTICLE 3 Term and modification

This understanding shall continue from date of signature ten years hence. It may by modified and/or extended by mutual agreement, and terminated by either party with sixty days' notice.

/s/ Robert E. Putz 8/8/84
Regional Director Date
Fish and Wildlife Service

/s/ Michael J. Penfold 8/27/84
State Director Date
Bureau of Land Management

APPENDIX B

BLM's Mineral Potential Classification System (from BLM Manual, Chapter 3131)
Mineral Potential Classification System I. Level of Potential O. The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources.

The "known mines or deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.

ND. Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

II. Level of Certainty

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within a respective area.

B. The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C. The available data provide direct evidence, but are quantitatively minimal to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

For the determination of No Potential, use O/D. This class shall be seldom used, and when used it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholithic (igneous intrusive), one can conclude, with reasonable certainty, that the area does not have potential for coal.

As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and/or mineral resources. It does not refer to or imply potential for development and/or extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

Appendix C

Oil and Gas Demand and Supply Relationships

The importance of potential oil and gas resources from this refuge is dependent on the hydrocarbon potential of the area, national need for additional sources of oil and gas, and the economics of exploring and producing any hydrocarbons that might be discovered. This Appendix provides a detailed review of the factors that have contributed to the present domestic oil and gas situation and possible future demand for oil and gas, which is directly linked to the national need for oil and gas resources from the refuge.

Domestic Energy Trends

The domestic energy situation, as it relates to oil and gas consumption and production, has changed dramatically since the early 1970s. In 1970, petroleum and natural gas supplied 44 and 33 percent (United States Department of Energy, Energy Information Administration, 1984), respectively, of the total energy consumed in the United States (figure 1). By 1977, petroleum accounted for nearly 49 percent of domestic energy consumption, and natural gas consumption had declined to approximately 26 percent of total energy demands. The relative contribution of both petroleum and natural gas declined through 1985, when petroleum supplied nearly 42 percent, and natural gas contributed approximately 25 percent of total energy demand. Figure 1 shows the contribution of each major primary energy source to total national energy demand in 1970, 1980, and 1985. Coal, nuclear, and geothermal energy were the primary forms of energy to increase their market share of total energy consumption during this time period, at the expense of petroleum and natural gas resources.

Total domestic energy consumption peaked at 78.9 quadrillion (QUAD) British thermal units (BTU) in 1979 and subsequently declined to 73.8 QUADS in 1985 (United States Department of Energy, Energy Information Administration, 1986). Over the 15-year period from 1970 to 1985, total primary energy consumption increased 11 percent, from 66.4 QUADS to 73.8 QUADS; however, the rapid increase in energy consumption and escalation in the cost of energy (the cost of energy more than doubled, from 1.35 constant 1972 dollar per million BTU in 1970 to 2.90 in 1981) during this time period resulted in a dramatic change in national energy consumption patterns. Total energy consumed per constant 1972 dollar of Gross National Product (GNP) ranged from 56,500 to 61,000 BTUs per 1972 dollar of GNP from 1960 through 1976 (United States Department of Energy, Energy Information Administration, 1985a). A decline in the intensity of energy utilization was realized in 1977, when total energy consumption dropped to 55,700 BTUs per dollar of GNP, and this downward trend continued through 1985, when energy consumption was reduced to 42,900 BTUs per 1972 dollar of GNP (United States Department of Energy, Energy Information Administration, 1986). The decline in energy consumption was led by the

FIGURE 1
PRIMARY ENERGY CONSUMPTION BY SOURCE

FIGURE 1A
1970
Total = 65.4 Quadrillion Btu

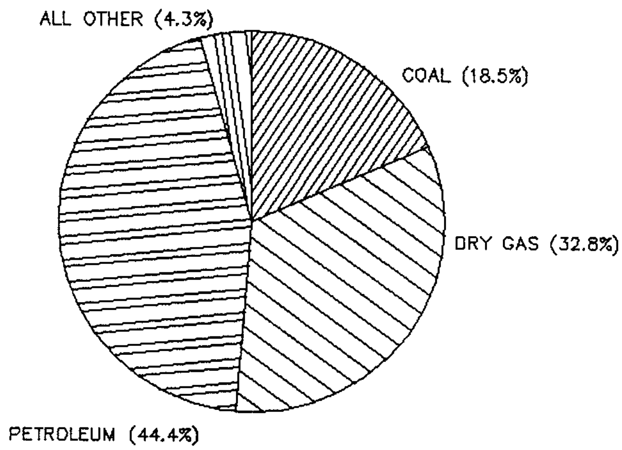


FIGURE 1B
1980
Total = 75 Quadrillion Btu

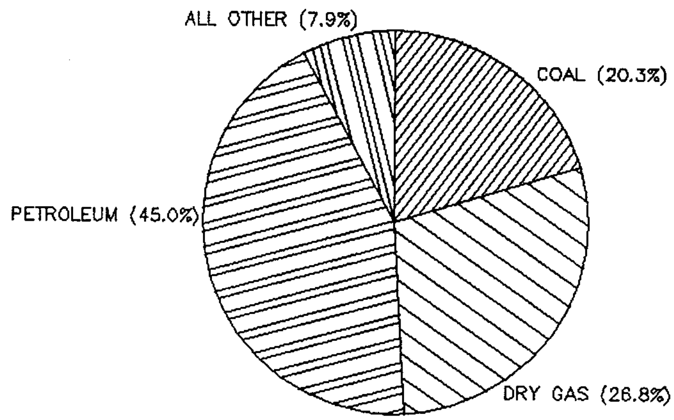
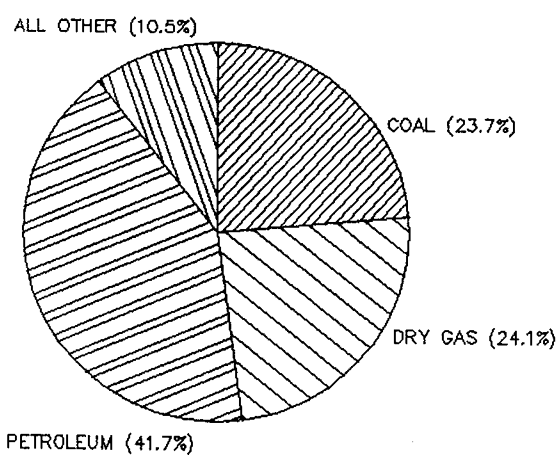


FIGURE 1C
1985
Total = 73.5 Quadrillion Btu



reduction in the intensity of petroleum and natural gas utilization. In 1985, only 68 percent as much petroleum and natural gas were consumed per dollar of GNP than in 1977, as compared to 77 percent for total energy consumption. The reduction in intensity of energy utilization was indicative of a national conservation effort which any be attributed to many factors, including: increased real energy prices, the increased service orientation of the economy, and changes in the mix of product production (United States Department of Energy, Energy Information Administration, 1985a).

Historical Oil and Gas Demand, Supply, and Price Relationships

The relationship between price and domestic petroleum supply and demand is shown in figures 2 and 3. Import prices utilized for petroleum in figure 3 are represented by the national average refiner's acquisition cost of imported crude oil, and wellhead prices are presented on the basis of the national average from all producing wells. Domestic crude oil prices were not completely decontrolled until January 1981 and, therefore, domestic wellhead prices do not follow import prices during the 1970s. Petroleum product demand rose throughout the early 1970s, until it peaked at 18.8 million barrels per day (MBPD) in 1978 (United States Department of Energy, Energy Information Administration, 1986a). Crude oil price increases began with the Arab oil embargo in 1973, and a second major price run-up was triggered in 1978 by the Iranian revolution and subsequent oil stock building in anticipation of world oil shortages. Real import prices peaked at $44.00 per barrel (1985 dollars) in 1980.

Domestic petroleum product demand began a downward slide in 1979 which continued through 1983. The Organization of Petroleum Exporting Countries (OPEC) members sought to maintain the higher prices, that resulted from oil price shocks of the 1970s, by production restraints. However, oil prices have steadily declined since 1981 as a result of slow economic growth with subsequent declining petroleum demand and excess world productive capacity (United States Department of Energy, Energy Information Administration, 1986b). Domestic oil prices in the second quarter of 1986 had declined to the lower teens in nominal terms, which is comparable to 1974 prices in real dollars. Figures 2 and 3 show that petroleum demand is sensitive to price and is characterized by long lags and high elasticities.

Domestic petroleum production has been much more stable than petroleum product demand. Figure 2 shows that Alaskan production, primarily from the North Slope, contributes a significant portion of domestic supply. In 1985, Alaska accounted for more than 20 percent of the national crude oil production (United States Department of Energy, Energy Information Administration, 1986a). Price increases of the 1970s provided incentive for exploration and production from higher cost areas such as Alaska. Foreign imports have been required to fill the gap between domestic supply and demand. Crude oil and petroleum product imports peaked in 1977, when net imports accounted for more

FIGURE 2
NATIONAL PETROLEUM DEMAND
AND SUPPLY 1970 – 1985

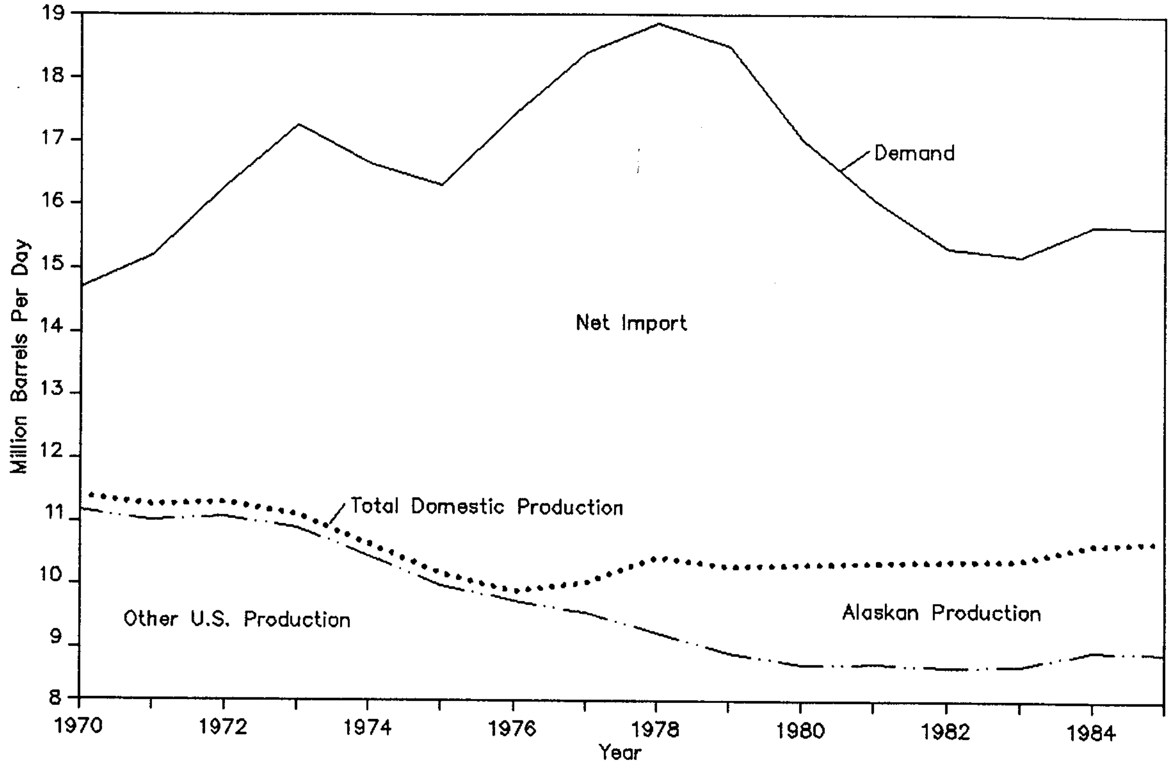
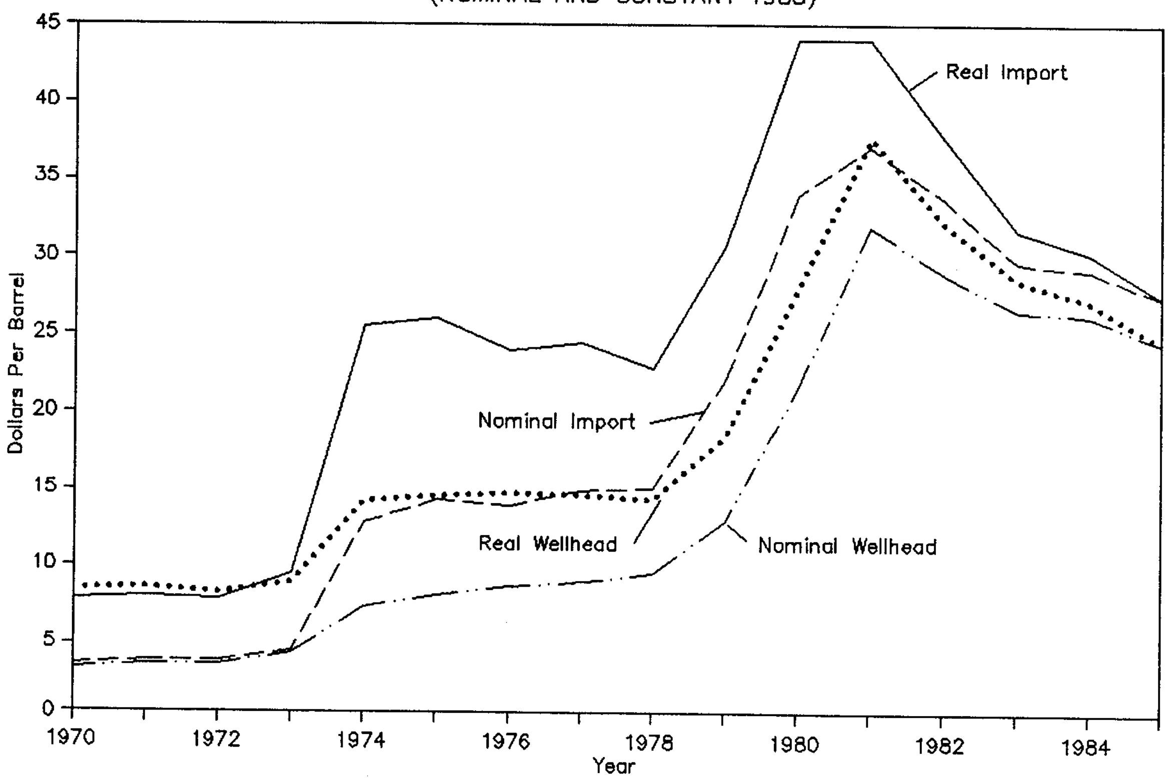


FIGURE 3
CRUDE OIL PRICES
(NOMINAL AND CONSTANT 1985)



than 46 percent of domestic petroleum consumption. Net petroleum import levels declined to 27 percent of product demand in 1985, but the United States still remains highly dependent of foreign petroleum supply sources.

The history of natural gas production and consumption in the United States is quite different from petroleum, and it has a direct bearing on gas pricing policies, demand, and supply relationships in the 1970s and 1980s (figures 4 and 5). Natural gas went from a little used waste by-product of oil production in the 1930s to a source of energy that supplied nearly 33 percent of national consumption in 1970 (figure 1). By 1970, gas was being delivered to consumers at prices well below those of competing petroleum products (United States Department of Energy, Energy Information Administration, 1984). Prices paid to gas producers by interstate pipeline companies were held at low levels through regulation by the Federal Power Commission, which resulted in increased demand and reduced incentives for producers to explore and develop new gas reserves. Regulated prices allowed intrastate transmission companies and distributors to bid natural gas supplies away from interstate carriers (Tussing and Barlow, 1984). The 1970s has been noted for the gas supply shortages in the midwest and northern states. Imported gas prices increased in a pattern similar to oil prices, but domestic prices remained under regulation. The Natural Gas Policy Act was passed in 1978, which allowed wellhead prices to increase and it deregulated certain categories of gas. Price increases provided incentives to explore and develop new sources of gas. Natural gas consumption started a sharp decline after 1980 under the influence of higher gas prices, a weak economy, warm winters, and, since 1981, falling oil prices (United States Department of Energy, Energy Information Administration, 1984). This trend continued through 1985, with the exception of a small increase in gas demand realized in 1981, which may be attributed to the strong economic growth in the national economy in that year.

Net imports of natural gas are primarily received through pipelines from Canada and Mexico, although there are some liquified natural gas (LNG) imports from Algeria. Net imports generally ranged near five percent from 1970 to 1985. Alaska is a relatively small producer of natural gas, ranging from approximately 100 to 325 billion cubic feet per year from 1970 to 1985 (United States Department of Energy, Energy Information Administration, 1985b). Alaska is, however, a net exporter of natural gas in the form of LNG, which is delivered to Japan. Huge gas reserves have been identified on the Alaskan North Slope, but this resource has not been commercially produced due to a lack of transportation infrastructure.

Future Oil and Gas Demand, Supply, and Price Relationships

From the review of historic petroleum and natural gas price, demand, and supply relationships, it is apparent that there have been fundamental changes, such as petroleum price deregulation and energy conservation efforts in the national energy market since the early 1970s that will likely affect future petroleum and natural gas production and consumption. At the present time,

FIGURE 4
NATIONAL NATURAL GAS DEMAND
AND SUPPLY 1970 – 1985

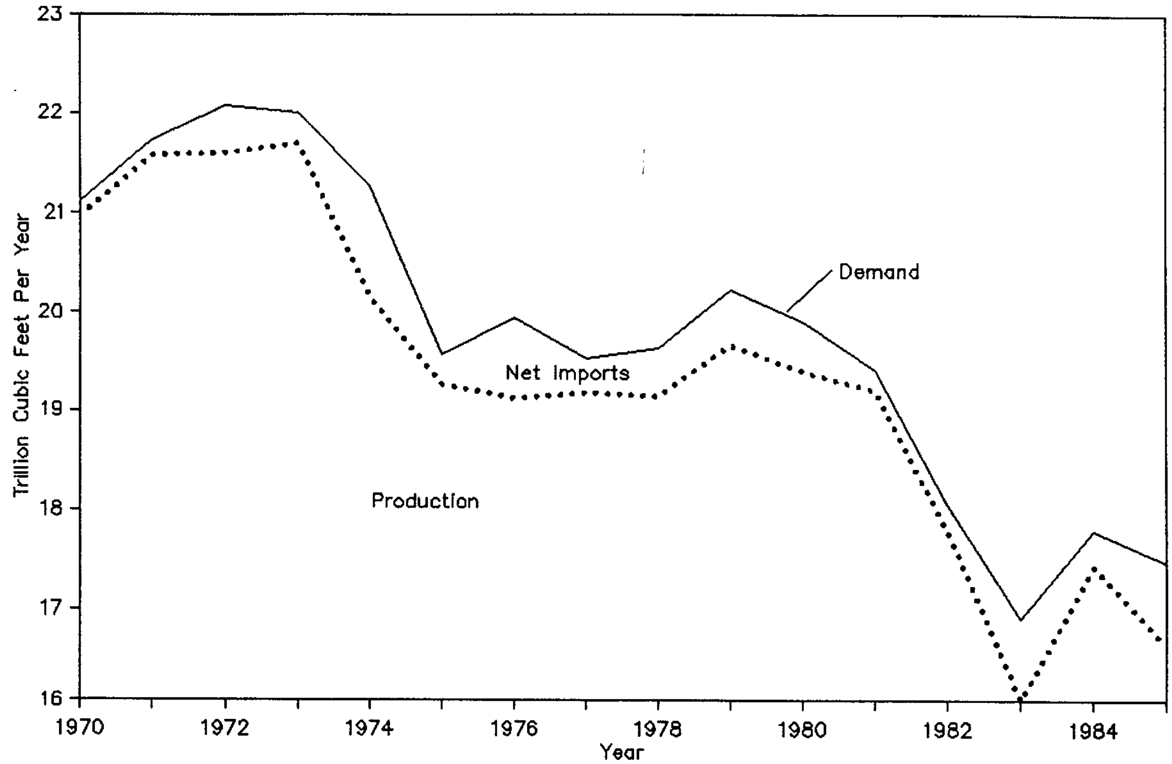
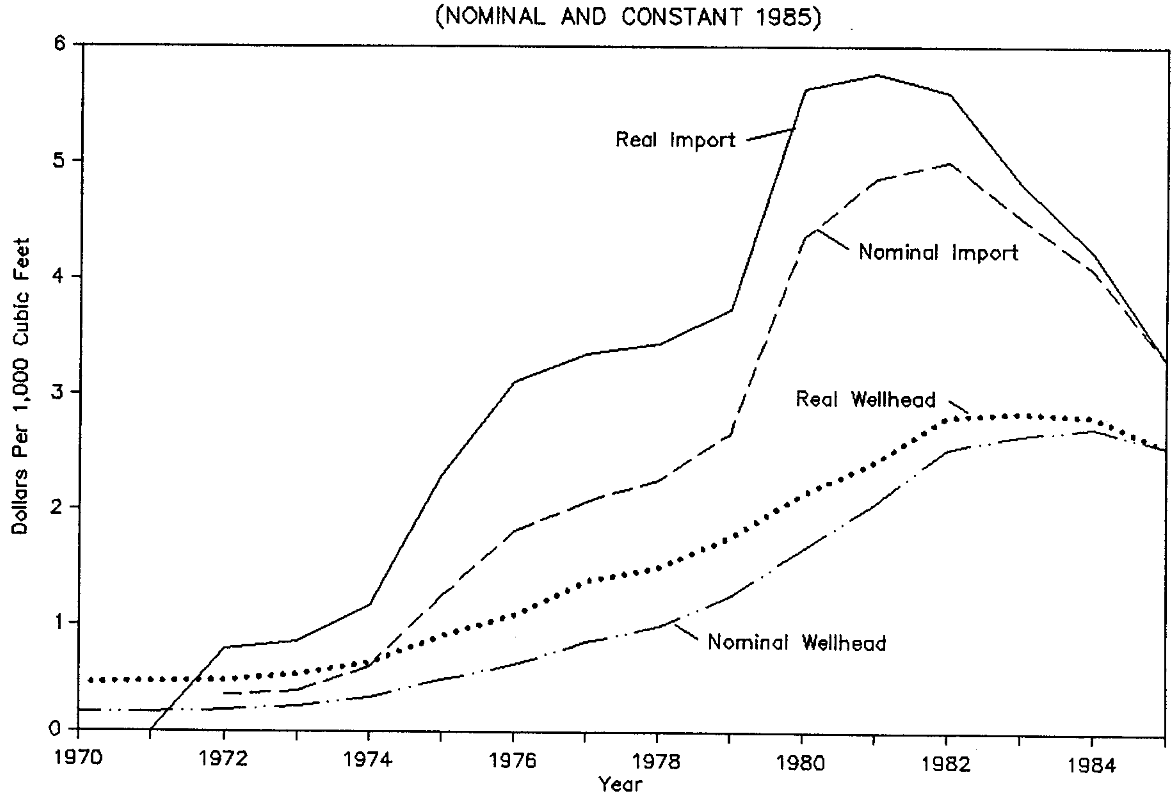


FIGURE 5
NATURAL GAS PRICES
(NOMINAL AND CONSTANT 1985)



the national petroleum market is directly linked to the world petroleum market by price and supply. The situation is characterized by excess productive capacity in the world market, a strong desire by exporting nations to sell petroleum to meet financial obligations, a time of relatively slow economic growth, and declining petroleum prices. The domestic natural gas industry is currently working off surplus reserves added during the early 1980s, but depressed prices have resulted in a sharp reduction in drilling which could have serious implications for future domestic gas production.

Implications of the petroleum price slide during the first half of 1986 are not yet fully discernable. Middle eastern nations have been unable to reach accord in setting and adherence to self-imposed oil production quotas. In the past, Saudi Arabia has taken the position as swing producer for OPEC, and thereby reduced production to maintain quota levels. However, Saudi Arabia changed policies in 1986 to concentrate on achieving a "fair market share" of the international petroleum market with little concern for output quotas. The strategy behind this policy was not disclosed, but speculation as to the potential motivation and results of this action includes:

1. Saudi Arabia is making a show of strength to discipline OPEC members that have cheated on production quotas and prices with hopes of bringing member and possibly non-member nations together as a unified market group;

2. Saudi Arabia sought to increase revenue, but underestimated the effects additional production would have on price;

3. Saudi Arabia is flooding the world oil market in an effort to eliminate producers with higher costs of production and thereby reduce competition;

4. Saudi Arabia is acting to reduce prices and stimulate growth in petroleum demand to reverse conservation efforts initiated in the late 1970s and 1980s.

In any event, a tremendous amount of uncertainty exists in the national petroleum industry, which has resulted in major financial restructuring. The most evident signs of restructuring are major employment reductions and reduced capital expenditures for exploration and drilling.

The interest in mineral exploration and possible development in this refuge is driven by the future national demand for oil and gas, the cost and availability of domestic supplies, and the hydrocarbon potential of the area. The rate of future economic growth and hydrocarbon prices will be the major determinants of petroleum and natural gas demand. Future domestic production is dependent on resource availability and market prices. However, political forces are having an increasingly important effect on world oil prices, which will ultimately dictate future market conditions. The instability in the world oil market results in tremendous uncertainty in predicting future hydrocarbon prices and market conditions. Table 1 presents three recent crude oil and natural gas price forecasts by the United States Department of Energy, a private research firm, and a major oil company. The prices shown in these forecasts are significantly lower than previous forecasts completed earlier in the 1980s. The range of oil prices projected in these forecasts is $18.00 to $42.00 (constant 1984 and 1985 dollars) per barrel in the year 2000. The high price range is approximately equivalent to the average annual refiner's acquisition cost of imported crude received in 1981 and 1982 (constant 1984 dollars). The range of prices projected for the year 2010 is $47.00 to $67.00 per barrel. These prices would be substantially above the peak levels paid in

Projections of future domestic petroleum and natural gas demand and supply conditions is presented in table 2. All three forecasts projected an upward trend in petroleum demand above current levels. Petroleum consumption is projected to range from 15.9 to 18.1 MBPD in the year 2000, and possibly increase to 19.4 MBPD by the year 2010. In comparison, domestic petroleum production is projected to decline to levels ranging from 6.1 to 8.9 MBPD by the year 2010. Domestic natural gas demand is projected to increase to a level ranging from 17.1 to 20.4 TCF per year by the year 2000 and then decline to a level of 16.7 to 18.3 per year by 2010. Domestic gas production is projected to follow a similar trend with domestic oil production and decline to levels ranging from 13.9 to 15.0 TCF by the year 2010.

Conclusion

National hydrocarbon markets have undergone substantial changes since the early 1970s. Energy conservation trends initiated by real price increases of the 1970s are expected to continue through the end of this decade and possibly beyond. However, future economic growth is expected to result in some increased demand for petroleum and natural gas, while domestic production of these finite resources is projected to decline. As a result, the United States will become increasingly dependent on foreign hydrocarbon sources to meet national requirements. New areas will need to be explored and any economically viable resources that are discovered will need to be brought into production in order to meet domestic needs. The potential contribution of this refuge to national oil and gas production is dependent on its resource potential and the potential cost at which any discovered hydrocarbon resources could be extracted and marketed within the constraints of future oil and gas prices.

TABLE 1

PETROLEUM AND NATURAL GAS PRICE FORECASTS[1]/

Reference	Crude Oil ($/Barrel)			Natural Gas ($/MCF)		
	1990	2000	2010	1990	2000	2010
U.S. Department of Energy, 1985[2]/						
Low Economic Growth	20.27	31.31	47.42	2.64	4.13	6.02
Reference Case	22.89	36.75	56.77	2.76	4.80	7.68
High Economic Growth	25.02	42.17	67.12	2.88	5.42	9.14
Data Resources Incorporated, 1986[2]/	16.91	34.32	49.99	1.69	3.80	5.76
Chevron Corporation, 1986[3]/						
Low Case	12.00	18.00	N/A	Rise to parity with fuel oil prices		
High Case	27.50	35.00	N/A			

1/ Some of the price estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.

2/ Reported on the basis of constant 1984 dollars.

3/ Reported on the basis of constant 1985 dollars.

TABLE 2

FUTURE DOMESTIC PETROLEUM AND NATURAL GAS DEMAND AND SUPPLY RELATIONSHIPS[1]
(See Table 1 for Price Forecasts)

Reference	Demand 1990	Demand 2000	Demand 2010	Supply 1990	Supply 2000	Supply 2010
	Petroleum (Millions of Barrels Per Day)					
U.S. Department of Energy, 1985						
Low Economic Growth	16.1	15.9	15.5	9.8	9.0	7.8
Reference Case	16.7	16.6	16.5	10.0	9.4	8.3
High Economic Growth	16.8	17.0	17.3	10.0	9.7	8.9
Data Resources Incorporated, 1986	16.9	18.1	19.4	9.5	7.3	6.1
Chevron Corporation, 1986	16.0	16.8	N/A	9.2	7.0	N/A
	Natural Gas (Trillion Cubic Feet Per Year)					
Department of Energy, 1985						
Low Economic Growth	18.6	18.8	17.2	17.4	16.1	14.7
Reference Case	19.1	19.7	17.4	17.6	16.3	15.0
High Economic Growth	19.5	20.4	18.3	17.9	16.6	14.7
Data Resources Incorporated, 1986	18.9	18.1	16.7	16.7	15.3	13.9
Chevron Corporation, 1986	17.3	17.1	N/A	N/A	N/A	N/A

1/ Some of the numeric estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.